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# NAVAL POSTGRADUATE SCHOOL

**MONTEREY, CALIFORNIA**

# THESIS

**MATURITY CURVE OF SYSTEMS ENGINEERING**

by

Roy Alphonso de Souza

December 2008

| | |
|---|---|
| Thesis Advisor: | Gary Oliver Langford |
| Second Reader: | Fernand Marquis |

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**13. ABSTRACT (maximum 200 words)**

Systems Engineering is a profession, a philosophy and a discipline that adopts an iterative and parallel problem identification and solution seeking process, coupled with a collaborative and integrated multi-disciplinary approach. It involves the lifecycle view of deriving functional solutions to the identified problems of the whole system and its dependants. The end state is in the satisfaction of the requirements, timeline and budget by the stakeholders. Systems Engineering requires the Systems Engineer to possess a series of traits that are academically and experientially acquired. The thesis looked at capturing these traits required via fuzzy logic scales and learning curve. The key observation was in the emphasis and need for certain traits at various levels of experience in the maturity cycle of a systems engineer. Learning curves were plotted to understand some of these traits. The experiential fuzzy logic scale developed was used to draw a relation to traits as desired in an employment of a Systems Engineer. Using the studies from the literature reviews on learning curves, various learning curves were obtained for selected traits. For the differences in the start point, i.e. when these traits are desired in an employment of a Systems Engineer, there is a relationship between the power and coefficient of the curves to the start point.

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# MATURITY CURVE OF SYSTEMS ENGINEERING

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Submitted in partial fulfillment of the
requirements for the degree of

**MASTER OF SCIENCE IN SYSTEMS ENGINEERING**

from the

**NAVAL POSTGRADUATE SCHOOL**
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# ABSTRACT

Systems Engineering is a profession, a philosophy and a discipline that adopts an iterative and parallel problem identification and solution seeking process, coupled with a collaborative and integrated multi-disciplinary approach. It involves the lifecycle view of deriving functional solutions to the identified problems of the whole system and its dependants. The end state is in the satisfaction of the requirements, timeline and budget by the stakeholders. Systems Engineering requires the Systems Engineer to possess a series of traits that are academically and experientially acquired. The thesis looked at capturing these traits required via fuzzy logic scales and learning curve. The key observation was in the emphasis and need for certain traits at various levels of experience in the maturity cycle of a systems engineer. Learning curves were plotted to understand some of these traits. The experiential fuzzy logic scale developed was used to draw a relation to traits as desired in an employment of a Systems Engineer. Using the studies from the literature reviews on learning curves, various learning curves were obtained for selected traits. For the differences in the start point, i.e. when these traits are desired in an employment of a Systems Engineer, there is a relationship between the power and coefficient of the curves to the start point.

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# I. INTRODUCTION

## A. OVERVIEW

It is often observed that skilled, practicing Systems Engineers perform more efficiently and more effectively than novices. They are also better at analyzing systems via reductionism (i.e., the decomposition of the system) and through their respective functions. However, the challenges in adapting traditional techniques for modeling behavior in complex domains confront both experienced and inexperienced people. Instructing first-time students in functional analysis is both vital and extremely unintuitive. Functional analysis allows the students to understand an unknown system via an appreciation of its functions. From the functional analysis, the systems engineer can understand the linkages to the functions and physical components.

Systems Engineering is a discipline that requires one to be equipped with an integrated level of knowledge to be of value to the project. It encompasses lifecycle issues, brings to bear the constraints and boundaries of systems thinking, and includes all lifecycle considerations that are significant to the success of the project. The main aim of Systems Engineering is to amalgamate individual components into a system entity (solution) that meets all requirements. Systems Engineering offers a structured, logical approach to achieving such an objective. With the use of the various Systems Engineering tools and processes, the experienced Systems Engineer multiplies his/her worth on the project, as he/she has a better appreciation of how the system functions through its sub functions.

Who is this experienced Systems Engineer? What experience or mentoring chain has he/she undergone to be what he/she is today? A relationship between various variables and the specific traits of a Systems Engineer is offered in this thesis.

## 1. Questions

This thesis investigates what it takes to be a good Systems Engineer, by analyzing their goals. The following questions were addressed:

1. What makes a good[1] Systems Engineer?
2. What are the desired traits of a good Systems Engineer?
3. What are the traits that companies/organizations look for in their employment of a Systems Engineer?
4. What are the key areas in which a novice Systems Engineer could be trained to become better?
5. How large is the gap that exists between a novice and a good Systems Engineer?
6. Can a model be built to characterize the essential traits of a good Systems Engineer?
7. Can a learning curve be constructed for the traits of a Systems Engineer?

## 2. Hypothesis

The thesis begins by establishing two driving hypotheses, namely:

### a. Hypothesis #1

There is a knowledge/ability gap between novice and expert Systems Engineers.

[1] A Good Systems Engineer is defined as one who is able to meet requirements as stipulated by the customer, meet schedule and one that is able to adhere to the allocated budget.

### b. Hypothesis #2

The gap between novice and expert Systems Engineers can be overcome.

## 3. Motivation

Other studies have investigated the criteria for successful System Engineers in comparison with other system professionals. Some researchers have examined the nature of acquiring knowledge via learning curves. Frank, Frampton, and Di Carlo (2007) compared Systems Engineers to Systems Architects and IT Architects, covering the traits required by each of these professions. Davidz (2005) and Frank (2000) covered the aspect of the Systems Engineer having embedded Systems Thinking. Sheard (1996) postulated twelve roles governing the Systems Engineer, while Andress (1954) and Towill (1985; 1990) covered various aspect of learning and their depiction with learning curves.

There is a need to understand the traits that are required by a Systems Engineer as he progresses along his profession. This thesis encompasses a list of required traits for a Systems Engineer.

# B. BACKGROUND

Riehle (2008) looked at various definitions of Engineering as captured by a variety of authors. From these, he encompassed a list consisting of sixteen concepts and practices that characterize Engineering. These sixteen elements, taken as a compound, differentiates engineering from other disciplines. His purpose to define a modern definition of Engineering was to allow accommodation of 'emerging engineering practices and not just the traditional engineering disciplines'. This led to his proposed modern definition of Engineering:

> Engineering is the organization, application, and management of settled (dependable) knowledge using the tools of science, mathematics, and logic, along with knowledge, experience, and artifacts derived from previous engineering efforts, for reconciling

conflicting forces/constraints, controlled within defined tolerances, to effect an economical, risk-averse, maintainable, fault-tolerant design toward the goal of a predictable outcome.

Systems Engineering is an Engineering Discipline. Systems Engineering was combined from the field of Value Engineering (1945) and systems thinking that was evolving in the 1950s (Langford, et.al, 2008). The generally credited time frame for the development of the discipline of Systems Engineering is the mid 1960s, and as such it is a fairly young field. This can be illustrated with the evolution of Systems Engineering in Figure 1 which illustrates how Systems Engineering has been covered by various authors throughout the decades. Commensurate with the Systems Engineering timeline are the various industrial and government directives that either resulted in or precipitated. .

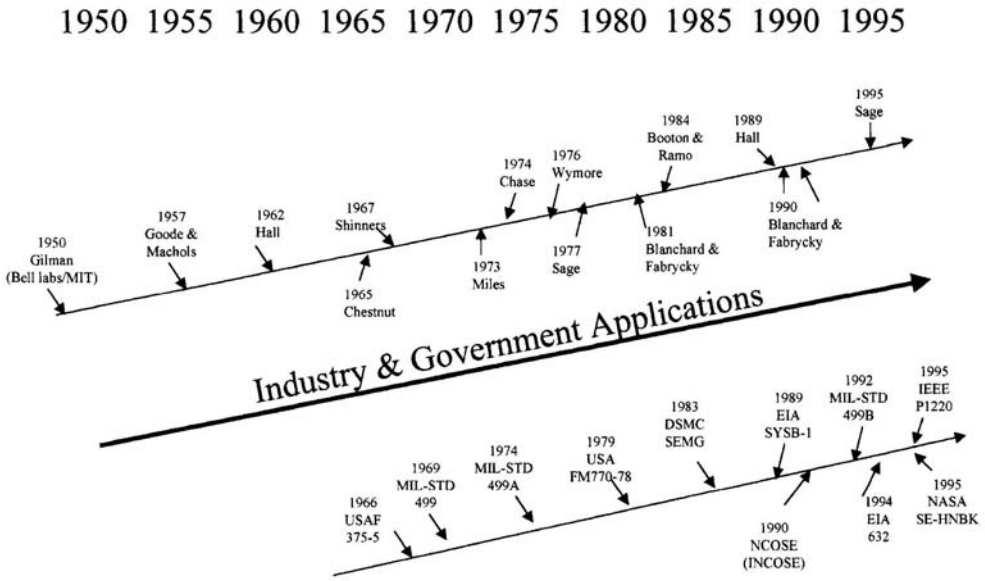


Figure 1 Evolution of Systems Engineering (After: Brill, 1998)

Studies have also defined and discussed the traits of a Systems Engineer (Sheard, 1996; Davidz, 2005; Jansma and Jones, 2006). There seems to be general agreement on a list of essential traits for a Systems Engineer that are

sought after by today's employers,[2] as well as being desired by practicing Senior Systems Engineers.[3] Generally, these two lists are highly correlated.

This common set of traits is necessary to conduct the activities required to do Systems Engineering on a project. Examples of these traits include the ability to perform requirements analysis, testing, and interfacing, among others. This thesis identified a list of parameters and measures/metrics that govern the required traits of a Systems Engineer.

There are many different permutations today that define Systems Engineering, with broad statements that overlap. Such common themes as interdisciplinary subject, iterative process, and systems approach, are among the most frequently described. One possible reason for the diversity for the definition of Systems Engineering is offered by Kasser and Massie (2001). They cite differences in the operating levels of the systems engineers as a primary determinant of the differences. As different operating levels grow, the usage of different vocabulary results in a variety of definitions. Despite the operations at the these different levels, the task being performed encompasses the processes of Systems Engineering.

The definition of Systems Engineering was determined by surveying the plethora of definitions and determining a taxonomy. This compendium of 28 definitions is found in Appendix A. The variety of definitions could imply the existence of a variety of traits required to perform Systems Engineering. All the definitions were bonded to refer to the traits of a Systems Engineer. The thesis lists these essential traits of a systems engineer. This goes on to the possible implication that at different levels, denoted by the years of experience of a Systems Engineer, different traits may be required. Concurrently, there are some similarities and additions to these definitions over the different periods

[2] This can be found in the list of traits of a Systems Engineers extracted from the study of classified ads as part of the research for this thesis.

[3] As part of this research, a survey was conducted of practicing Systems Engineers in the Academic and Industry arenas to ascertain their views on what makes a Good Systems Engineer.

considered (1960s to 2000s). This possibly implies that there are Systems Engineering activities being carried out over the decades that have not changed. As we progressed over time, we refine the definition to emphasize other activities within Systems Engineering. This thesis will show that with different years of experience of a Systems Engineer, different traits are required.

This section of the background of Systems Engineering looks at the questions posed in Figure 2:

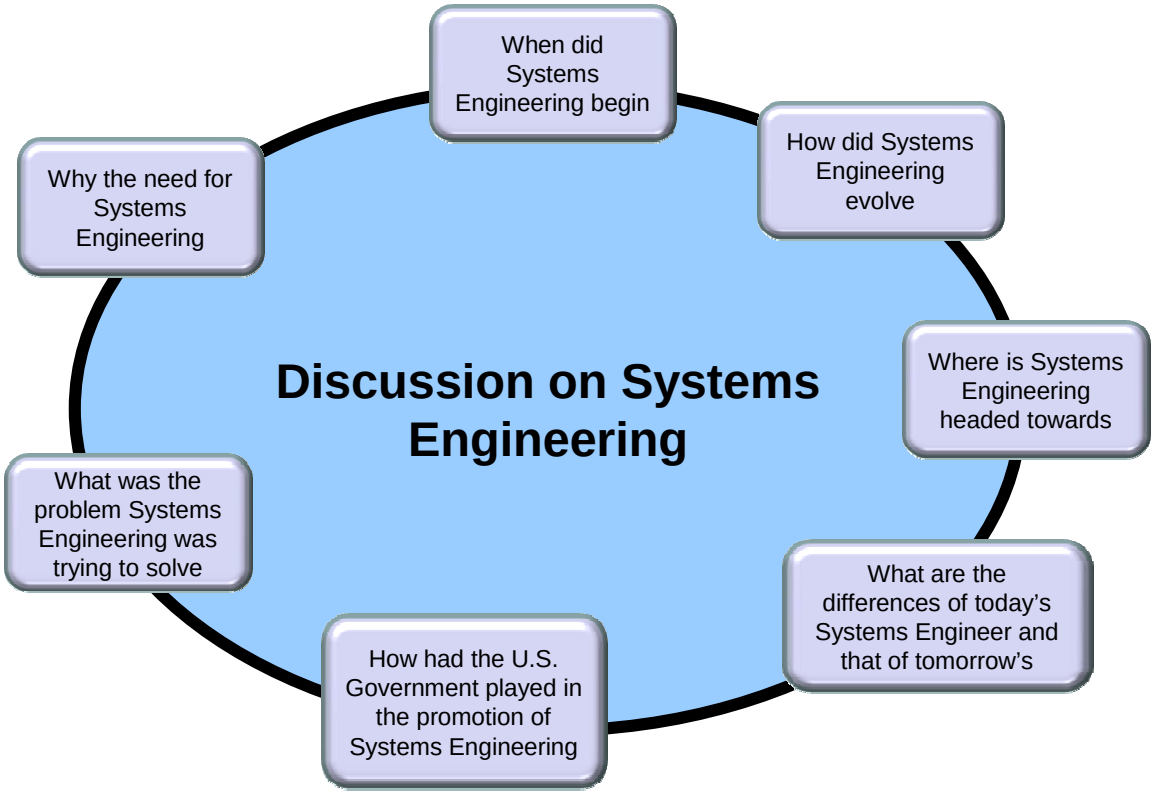
Discussion on Systems Engineering
When did Systems Engineering begin
How did Systems Engineering evolve
Where is Systems Engineering headed towards
What are the differences of today's Systems Engineer and that of tomorrow's
How had the U.S. Government played in the promotion of Systems Engineering
What was the problem Systems Engineering was trying to solve
Why the need for Systems Engineering

Figure 2 Questions that Frame the Discussion about Systems Engineering

### 1. In the Beginning….

When God wanted Noah to build an Ark, He had a plan. He had considered what was to be done and systematically gotten Noah to construct the Ark that would preserve his family and a breed of every animal. This…….. is Systems Engineering in practice.

To claim the first original use of the term Systems Engineering, Hall (1962), goes on to mention that the term was first coined and used by Bell Laboratories in the 1940s. He goes on to mention that the first attempt to formally teach the Systems Engineering was made in 1950 at the Massachusetts Institute of Technology by Mr. G. W. Gilman, then Director of Systems Engineering at Bell Laboratories, Inc.

On the other hand, Kossiakoff and Sweet (2003) and Brill (1998) highlight the lack of a period to be correlated to the origins of Systems Engineering.

## 2. Why the Need for Systems Engineering?

> Given a context, system engineering establishes a framework to support a process with which we practice with consistency and, hopefully, completeness…. (Boarder, 1995)

As in the process of Systems Engineering, it is necessary to identify the need for a particular situation, based on the problem that needs to be rectified.

Table 1 Summary for the Need for Systems Engineering

| S/N | Source | Why the Need |
|---|---|---|
| 1 | Parnaby (1995), then President of Luca Industries | The complexities of today's products and the techniques needed to make them have made Systems Engineering methods essential to effective competition |
| 2 | Lewkowicz (1998) | Very large integrated systems have always posed special problems for engineers. "Systems Engineering" has evolved as a discipline in order to meet these challenges by providing a structured, top-down design and development methodology for the engineer. |
| 3 | Barber (1998) | Systems Engineering is at the heart of product development and improving the performance of this discipline is key to organizational success |

| S/N | Source | Why the Need |
|---|---|---|
| 4 | Chiang (2003) adapted from Arthur (1993) | Fast occurring changes, broad impacts, non linear interactions. Overall, the drive is for a strong profession that is structured and ordered in its approach to complex systems |
| 5 | Honour (2004) | The results of the study indicate that optimal SE effort is approximately 15 to 20% of the total project effort. |
| 6 | Goncalves (2008) | Systems Engineering is a critical capability for our organization's business following good growth in business but also because of risks in certain areas |

Table 1 outlines the various citations on the need for Systems Engineering. Systems Engineering is needed for its ability to deal with complex systems thus leading to the sustainment of the industry's competitive advantage with the structured process.

Systems Engineering emerged due to the need to solve the problems of the integration of hardware and software issues in Software Engineering. To name a few, the activities involved in the process allowed the systematic consideration of issues like stakeholders identification, requirements identification and integration parameters to be carried out. This allowed the complexity of the integration between hardware and software to be managed (Langford, 2008).

### 3. Why is the Government Involved?

The need for Systems Engineering is evident from the intervention of the U.S. Department of Defense in creating standards to assist in the embracement of Systems Engineering for the weapons acquisition process.

With the growth of industrialization after World War II, systems grew to complexity. As such, the processes and tools as offered by Systems Engineering were deemed to be useful in dealing with these systems. The post-World War II period saw the experiences and lessons acquired during the war being used for the newer acquisition for defense. Systems Engineering was tagged as a useful component for the acquisition of these weapons systems.

As depicted in Figure 1 the publication of the Air Force Systems Command Manual 375-5 (AFSCM 375-5), System Engineering Management Procedures in 1966:

> …prescribes the management policies and procedures to be followed in the establishment of requirements for, and in the design, development, test, operation, and maintenance of future Air Force systems… (Gelbwaks, 1967)

With the AFSCM 375-5, the military standards and industrial standards arena saw subsequent introduction of other standards on the practice of Systems Engineering for systems. Led by the U.S. Air Force (shown in Table 2), who was responsible for the development of satellites, the U.S. Air Force developed the Systems Engineering Management Procedures in order to promulgate the practice of Systems Engineering for their complex satellite building efforts.

Table 2 Genealogy of Systems Engineering Military Standards and Handbook (Adapted from Brill, 1998)

| S/N | Standard / Handbook | Origins | Contents |
|---|---|---|---|
| 1 | Handbook 375-5 (1966) – System Engineering Management Procedures | U.S. Air Force | Describes in great detail a Systems Engineering process. |
| 2 | MIL-STD-499 (1969) – Systems Engineering Management. | U.S. Air Force | The standard superseded the “how-to” content of 375-5 and was intended to assist Government and industry in defining the Systems Engineering effort of defense acquisition programs. |

| S/N | Standard / Handbook | Origins | Contents |
|---|---|---|---|
| 3 | MIL-STD-499A (1974) | U.S. Air Force | A revision to MIL-STD-449 to provide program managers criteria for evaluating engineering planning and output, a means for establishing an engineering effort and a Systems Engineering Management Plan (SEMP). |
| 4 | U.S. Army published Field Manual, 770-78 (1979) – Systems Engineering. | U.S. Army | The manual describes a system engineering process and presents extensive Systems Engineering "how-to" guidelines for implementing a Systems Engineering process and managing system engineering. |
| 5 | MIL-STD-499B (1992) – Systems Engineering Handbook | U.S. Air Force | The standard provided a more comprehensive description of a Systems Engineering process and its management to include an outline for a Systems Engineering Management Plan (SEMP). |

The successes (and failures) achieved over the years on the use of Systems Engineering in the U.S. Department of Defense resulted in a memo[4] issued on 30 March 2004, which stated that:

> …All programs responding to a capabilities or requirements document….. shall develop a Systems Engineering Plan (SEP) for Milestone Decision Authority (MDA) approval in conjunction with each Milestone review…….

[4] Retrieved on 30 Sep 08 – Implementing Systems Engineering Plans in D0D – Interim Guidance. http://sepo.spawar.navy.mil/Implementing_SE_Plans_In_DoD_Interim_Guidance.pdf

## 4. Where are we Headed ?

It is certain that the systems being managed will become more complex in the future. There will be a need for the Systems Engineer to manage these increasingly complex systems. Therefore, the required Systems Engineering tools will need to be more robust.

Booton and Ramo (1984) observed that Systems Engineering will progress in the direction of increased capabilities of analytical tools used by Systems Engineers and will increase in complexity following the systems under consideration.

Mintz (1994) covered the growing complexity of the systems faced and thus the need for developing Systems Engineering techniques. He stated that Systems Engineering will be developed via use of computer-aided Systems Engineering tools that support the Systems Engineering Process, formalize specification models, and merge commercial and Department of Defense standards. This amalgamation responds to an increase in the commercial and a decrease in the government businesses, third-party evaluation and certification of processes and professional recognition of Systems Engineers.

From the perspective of learning from the problems of Systems Engineering, Bar-Yam (2003), suggested two strategies of confining conventional Systems Engineering processes to “not-too-complex” projects and “an evolutionary paradigm for complex Systems Engineering that involves rapid parallel exploration and a context designed to promote change through competition between design implementation groups with field testing of multiple variants”.

In addressing the tools required for growing complexity, Chiang (2003) talked about the Systems Engineering support tools evolving and how these tools can subsequently contribute to the scientific study of complexity.

Boarder (1995) added that:

> Given a context, system engineering establishes a framework to support a process with which we practice with consistency and, hopefully, completeness.

### 5. Tomorrow's Systems Engineers… Handle Complexity

The nature of tomorrow's systems are complex.

Using the classical approach to tackle a problem may subsequently require additional 'support tools'. Chiang (2003) recommended expanding the role of Systems Engineers to handle more complex systems to prepare for tomorrow.

Chen and Clothier (2003) outlined the need for improving via complementing the current Systems Engineering process with practices of concurrent engineering, consideration of a Systems Engineering infrastructure, and modern Systems Engineering management for engineering activities and data / information across projects and systems domains. These would assist the organization and management to deal with the high complexity of systems "evolutions and improve its architecture practice".

Dahmann and Baldwin (2008) went on to mention that the U.S. Department of Defense has recognized the need to "manage and engineer ensembles of systems to address use capability needs" due to the increased complexity of tomorrow's systems.

## C. METHODOLOGY OF THESIS

The methodology[5] section will cover the activities associated with the thesis, the methodology used and the implications associated with that methodology.

[5] Definition of methodology – A System of Methods and Rules to facilitate the collection and analysis of data. (Hart, 1998)

## 1. Methodology Overview

A qualitative approach in acquiring and managing the data was used for this analysis. A quantitative tool was used to examine and evaluate the data.

The qualitative approach was intended to sort the acquired traits of a Systems Engineer relative to two variable, i.e. years of experience and annual income. Quantifying the SE traits challenged the traditional means of analysis due to their overlap and underlap in defining properties. Therefore, a fuzzy logic approach was used to understand the relative quantization of these traits.

An overview of the activities covered by the thesis spans history, analysis, and common platform, that of a three-pronged approach, as depicted in Figure 3. The methodology can be referred to in Figure 4. A triangulation[6] (Silverman, 2005) method of comparison was used to corroborate the various data collected from the classified ads, surveys and literature review. The method of triangulation was that used by Frank, Frampton, and Di Carlo (2007).

In the process of establishing a methodology for the thesis, a Systems Engineering approach was taken to consider the different set of activities required in establishing the process to be taken. This is depicted in Figure 5. The process involved a set of activities, coupled with inputs and outputs from each process. A set of interrelationship was established within this process, between the activities, inputs and outputs. Worth mentioning, it was established that the Literature Review was an important input to be used at almost all of the activities in the process. This was essentially true as information from the varied sources (shown in Figure 8 page 26) allowed the activities to be performed to develop the desired output.

[6] Triangulation – the comparison of different kinds of data (quantitative and qualitative) and different methods (e.g., observation and interviews) to see whether they corroborate one another (Silverman, 2005, p. 380).

The methodology for this thesis covers the need to have the required data (traits) for the initial start up. This was obtained via different data sources, such as classified ads, surveys sent to practicing Systems Engineers and the literature reviews conducted.

**Data**. The data[7] gathering phase was deemed to be complete once a noticeable pattern evolved in each of the three data gathering modes. This is akin to the method of doing a meta analysis, less the presence of any statistical comparison. The noticeable pattern evolution was similar to the idea given by Silverman (2000), on the establishment of categories (outstanding repeated elements) in the analysis of raw data. Frank, Frampton and Di Carlo (2007) also used this idea in their paper.

In the use of the classified ads to gather data of the traits of a Systems Engineer, a relationship finding mode was used in order to establish possible relationship between the traits and the variables of income and years of experience.

[7] Definition of Data – the traits of the Systems Engineer, years of experience of the Systems Engineer with the associated traits, annual income, definitions of Systems Engineering. The sources of these data were the classified ads, survey and literature review.

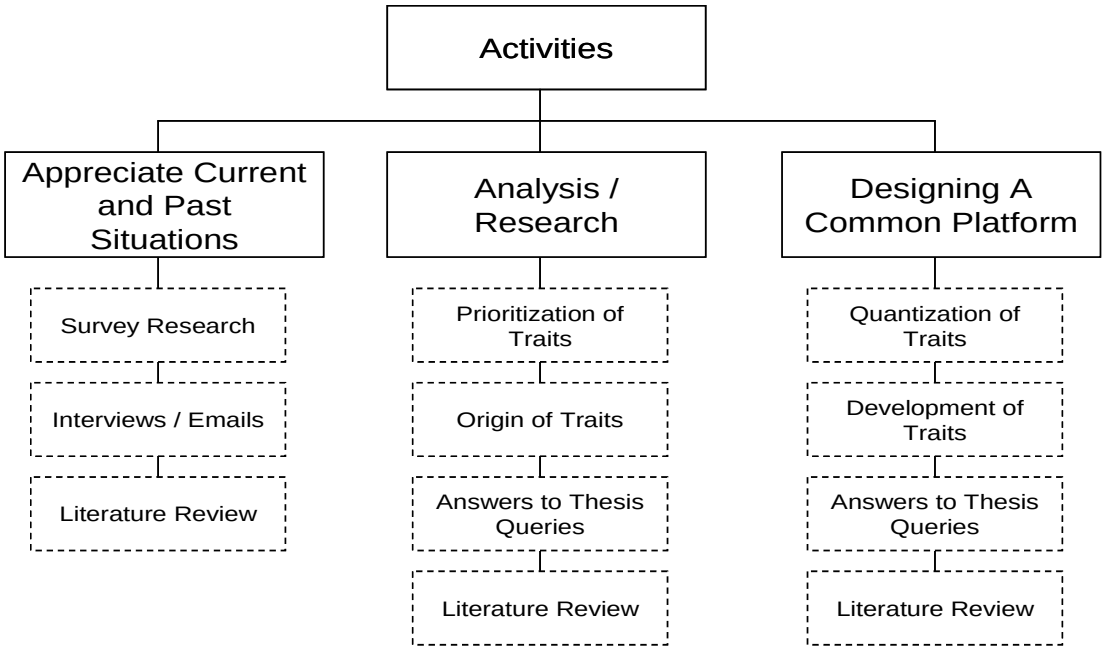


Figure 3 Activities of Thesis

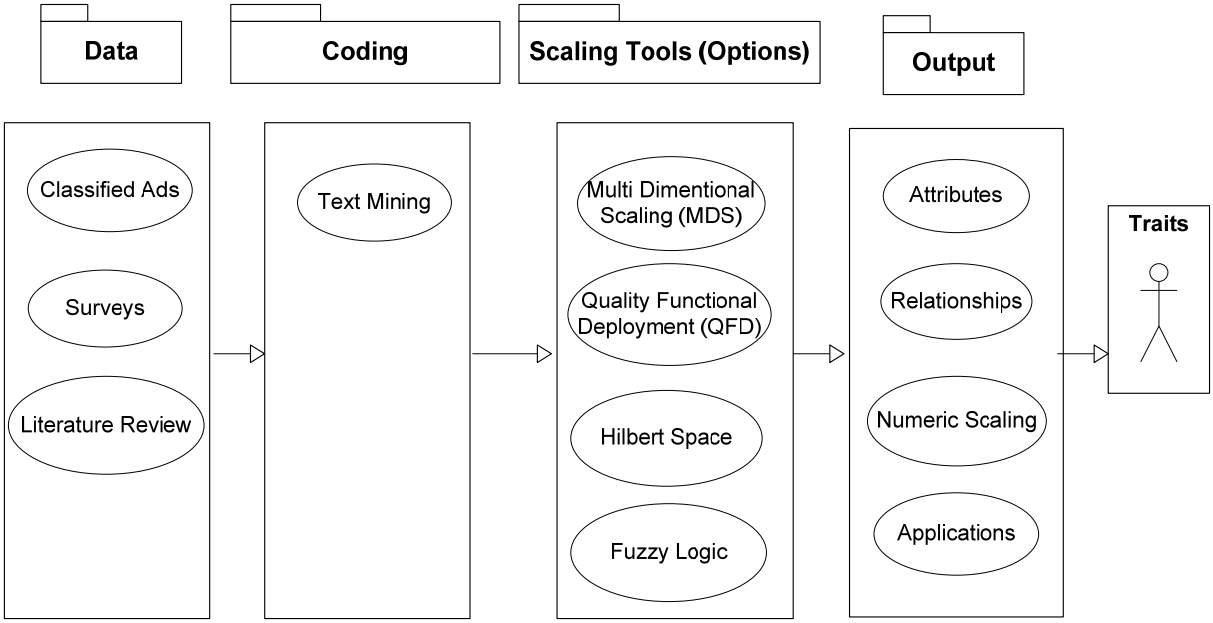


Figure 4 Methodology of Thesis

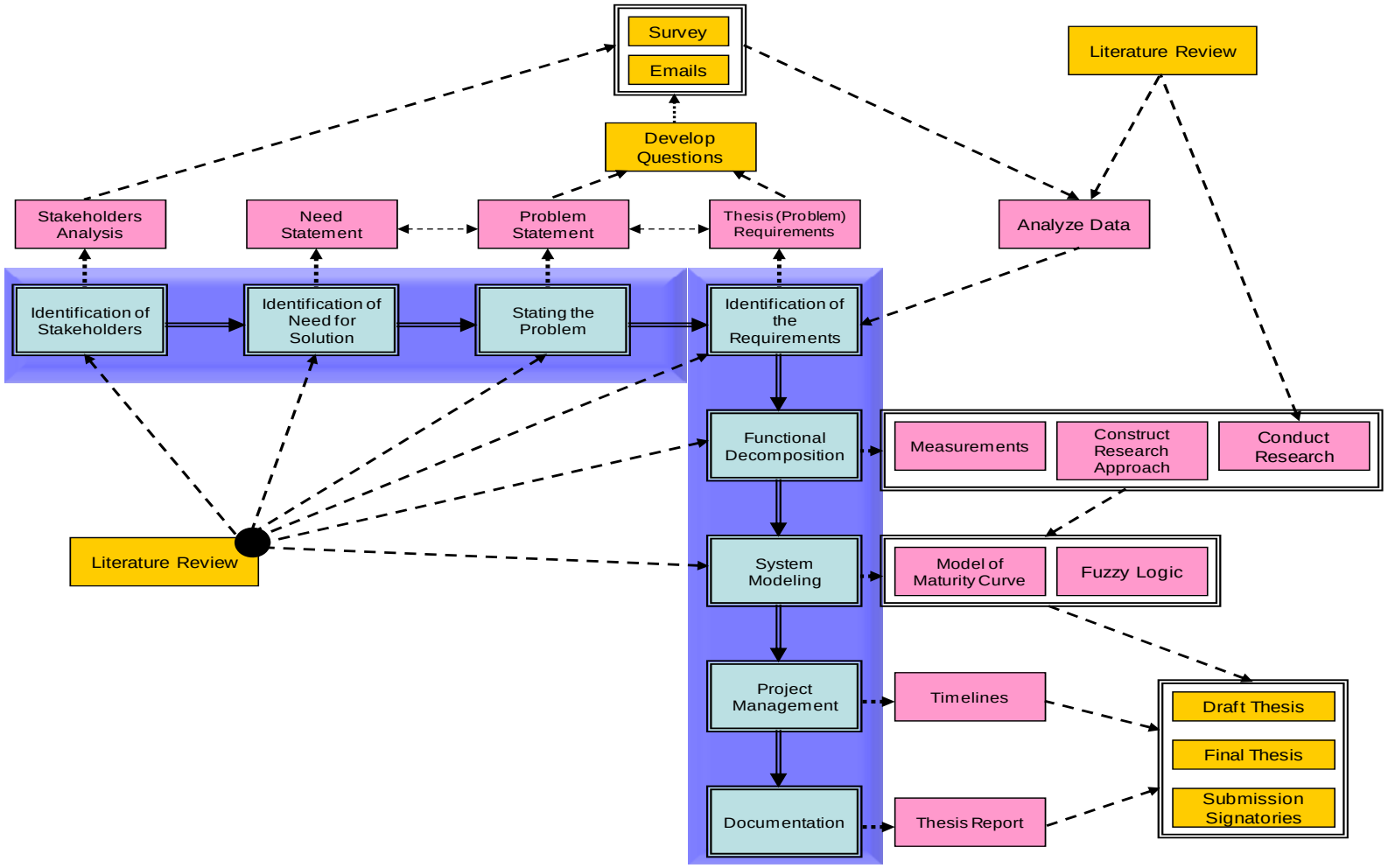


Figure 5 Systems Engineering Activities

**‘Modified’ Text Mining**. The definition of text mining is offered below:

> Text mining tries to solve the crisis of information overload by combining techniques from data mining, machine learning, natural language processing, information retrieval, and knowledge management. (Feldman and Sanger, 2006)

The idea of text mining was adopted to manage the large number of traits that would be expected to be retrieved from the survey, classified ads and literature review. The modification here refers to the absence of the use of any automated system in the collection of the naturally occurring text.

**Scaling Tools**. Several possible scaling tools were listed in order to ascertain their suitability to conduct scaling of the gathered categorized data. Examples included Multi-Dimensional Scaling (MDS), Quality Functional Deployment (QFD), Hilbert Space and Fuzzy Logic. The sole task of these tools was in the quantifying of the gathered traits against another variable, e.g. years of experience or annual income.

Fuzzy Logic was chosen as a good overview of the gathered traits that could be visually seen on a given arbitrary quantitative scale. The implication of this selection showed some possible error term, which is discussed in the Implications of Methodology of Thesis Section (p. 18). Fuzziness implies that there is no clear demarcation of boundaries within a collection of objects, as opposed to the concept of dichotomy, where clear sets of boundaries exist (Pedrycz and Gomide, 2007).

**Outputs**. Once the data gathering and scaling tool selection was done, attributes, relationships, numerical scaling and applications were looked into while creating the various fuzzy scales. These were considered as the output for the thesis where the traits and some gathered variables (e.g. years of experience, annual income) were scaled in the chosen scaling tool and the applications of these relationships looked into. As associated with the scaling

tools, the selection of the scaling tool showed some possibly error term, being elaborated in the Implications of Methodology of Thesis Section (p 18).

## 2. Linking Research Questions and Methods

Mason (2006) offers a simple way of linking the research questions to the methods of data exploration. Table 3 outline this linkage between the research questions for this thesis and the methods used:

## 3. Implications of Methodology of Thesis

### a. Error Term

Within the scaling option chosen (i.e., Fuzzy Logic), it was inevitable that a possible standard deviation would exist within the scale used; this was identified as a possible source of error. A squared summation of the error was rooted in order to appreciate the associated error. As such, the reader is advised to associate the number of years of experience for a given trait with this associated error. The associated error is given as:

$$\text{Standard Deviation (Error Term)} = \sqrt{\frac{(\text{Interval Size}_{\#1})^2 + (\text{Interval Size}_{\#2})^2 + \ldots\ldots + (\text{Interval Size}_{\#n})^2}{n}}$$

$$\text{Standard Deviation (Error Term)} = \sqrt{\frac{(2)^2 + (3)^2 + (5)^2}{3}}$$

$$\text{Standard Deviation (Error Term)} \approx 3.6 \text{ years}$$

The fuzzy logic scale thus used has an associated error term of about 3.6 years.

### b. Usage of Classified Ads for Traits Requirement

The requirements of a Systems Engineer as printed in the classified ads were chosen to allow the data to be as ‘naturally occurring’ (Silverman, 2005) as possible, without any special setup of interviews and specific environments.

In the use of the classified ads as a means to collect the desired traits of a Systems Engineer, it was assumed that the originator was well versed in the desired requirements. The Use-Case model of the Job Application process is shown in Figure 6. The basic set of actors in this process are the job applicant and the HR Manager (assumed to be the originator of the ad). The HR Manager understands the needs of the company and crafts the job requirements (possibly with another Systems Engineer). These requirements are then advertised. The job applicant understands the basic requirements as set out in the advertisement, and submits an application. If the application is reviewed favorably, an interview is set up.

Further on, an 'Overlap Theory' was developed with regard to the various scenarios that the hiring process can engender. This is depicted in Figure 7.

The various scenarios depict the hiring and non-hiring situations. The hiring process involves a certain degree of overlapping of the requirements mentioned in the classified ads and the abilities of the applicant, ranging from 0% to possibly, 100%.

Table 3 Linking Research Questions to Methods (After: Mason, 2006)

| S/N | Research Question | Data sources | Justification |
|---|---|---|---|
| 1 | What makes a good Systems Engineer? | • Surveys<br>• Literature Review | • Survey will provide the industrial experience of the respondents of successful Systems Engineers<br>• Literature Review will contain results of studies or surveys conducted on successful Systems Engineers |

| S/N | Research Question | Data sources | Justification |
|---|---|---|---|
| 2 | What are the desired traits of a good Systems Engineer? | • Surveys<br>• Literature Review | • Surveys will serve as a means to seek the opinions of the respondents on traits of a good Systems Engineer<br>• Literature Review will contain results of studies or surveys conducted on successful Systems Engineers |
| 3 | What are the traits that companies/organizations look for in their employment of a Systems Engineer? | • Surveys<br>• Classified Ads | • Survey results will give an indication of the desired traits, since the respondents chosen are practicing Systems Engineers<br>• The requirements in the Classified Ads for Systems Engineers reflect the desired traits |
| 4 | What are the key areas in which a novice Systems Engineer could be trained on to become better? | • Classified Ads<br>• Fuzzy Logic Experiential Scale | • Classified Ads, with the output of the Fuzzy Logic Experiential Scale, will chart the difference between experienced and novice Systems Engineers. This will then be used to ascertain the differences in the traits between them |
| 5 | How large is the gap that exists between a novice and good Systems Engineer? | • Classified Ads<br>• Fuzzy Logic Experiential Scale | • Classified Ads, with the output of the Fuzzy Logic Experiential Scale, will chart the difference between experienced and novice Systems Engineers. This will then be used to ascertain the differences in the traits between them |

| S/N | Research Question | Data sources | Justification |
|---|---|---|---|
| 6 | Can a model be built to characterize the essential traits of a good Systems Engineer? | • Classified Ads<br>• Fuzzy Logic Experiential Scale | • Classified Ads, with the output of the Fuzzy Logic Scale, will chart membership of the highlighted variables of annual income and years of experience of the Systems Engineer. This will shed some light on the traits that are required at the different levels of experience |
| 7 | Can a learning curve be constructed for the traits of a Systems Engineer? | • Literature Review | • Literature Review of learning curves, traits will assist to form a construct to the relationship between the parameters in question. |

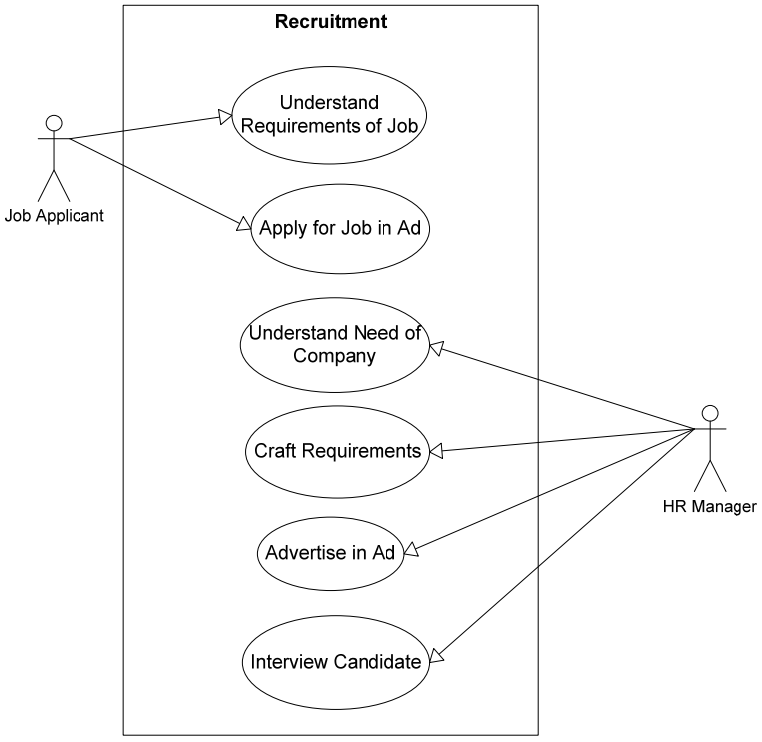


Figure 6 Use-Case Diagram for Job Application

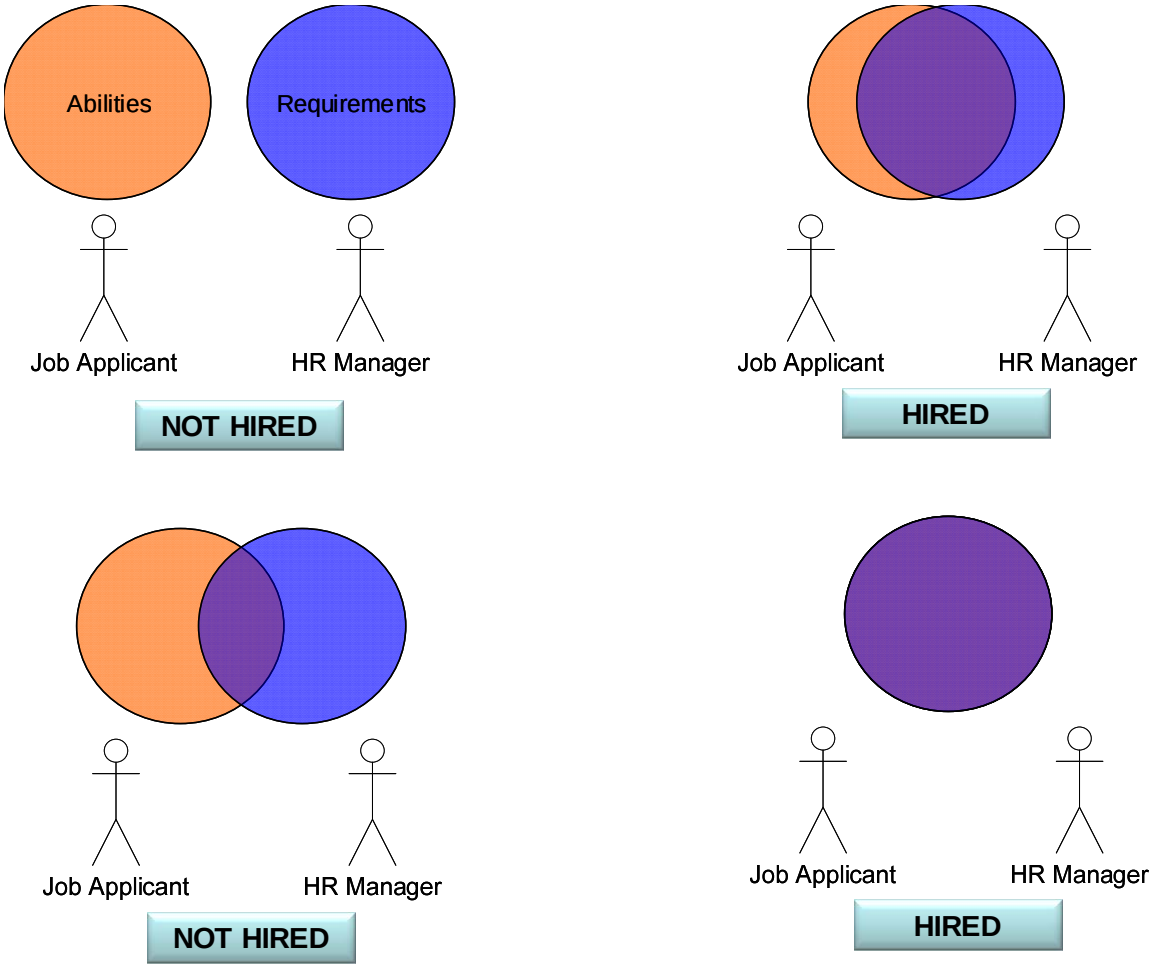


Figure 7 Various Scenarios of Overlap Theory

This 'Overlap Theory' is used to show that, with the following possible areas of concerns (Table 4), the process of advertising in the classified ads does reveal some error in the crafting of the desired Systems Engineer requirements. Subsequently, the hired Systems Engineer may possibly not have the full range of desired traits.

Table 4 Areas of Concern for Classified Ads

| S/N | Area of Concern | Details | Implications |
|---|---|---|---|
| 1 | Need of Organization | The office assigned to comprehend the need of the potential hired Systems Engineer may misunderstand the intended need | Inaccurate requirements specified in ads |
| 2 | Interpretation of Needs to Requirements | The requirements statements may not cover the needs due to misinterpretation | Inaccurate requirements specified in ads |
| 3 | Shrinking Requirements to Classified Ads | Advertising space cost money. As such, there might be a selection of 'only the necessary' requirements to be submitted for publication in the classified ads | Inaccurate requirements specified in ads |
| 4 | Ability matching to Classified Ads | The applicant may try to match as many as possible of his abilities to the requirements printed in the classified ads, thus may not fulfill all of them | May not be the suitable candidate hired |

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# II. LITERATURE REVIEW

> To demonstrate skills in library searching; to show command of the subject area and understanding of the problem; to justify the research topic, design and methodology. (Hart, 1998, as cited in Silverman, 2005)
>
> After some initial groveling, know what you are looking for. Approach the literature with questions and remember that your goal is to advance it, not simply to marvel at its wonders. Seek an appropriate balance between appreciation and advancement of the literature. (Marx, 1997, as cited in Silverman, 2005)

## A. METHODOLOGY OF LITERATURE REVIEW

### 1. Methodology of Literature Review

As in all research, literature review is an important phase where the works of the past and the present are given consideration and used as data points for one's work. The above two quotes clearly illustrate the essence of a literature review: gain a thorough grounding in the subject area to understand the problem and advance what has already been done and considered by others. As depicted in Figure 5, Literature Review is the data gathering activity most connected to the other steps for this thesis.

Figure 8 outlines the sources used for the literature review in order to establish a firm foundation to effectively evaluate works in relation to the thesis (Marx, 1997, as cited in Silverman, 2005):

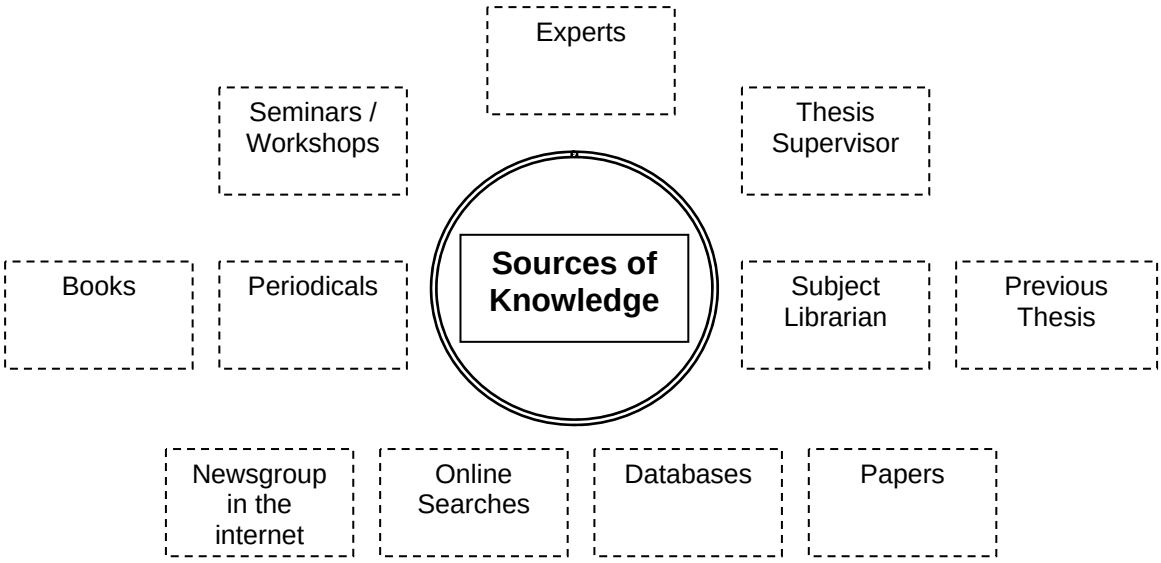


Figure 8 Sources of Knowledge for Literature Review (After: Marx, 1997, as cited in Silverman, 2005)

During the survey conducted of practicing Systems Engineers to determine the ideal traits of the profession, additional source material (i.e., the most cited articles/books/papers on the topic) was also obtained. This allowed the literature review to encompass the most relevant content for the research. Figure 9 illustrates the Identification Explore Recognition Clarify-Referencing Cite (IERC-RC) literature methodology used for this thesis. The methodology is iterative in nature, cycling between the IERC phases until a satisfactory reference is found. In order to maintain a good index of the references found, a management system (RefWorks) was utilized to manage the database of references.

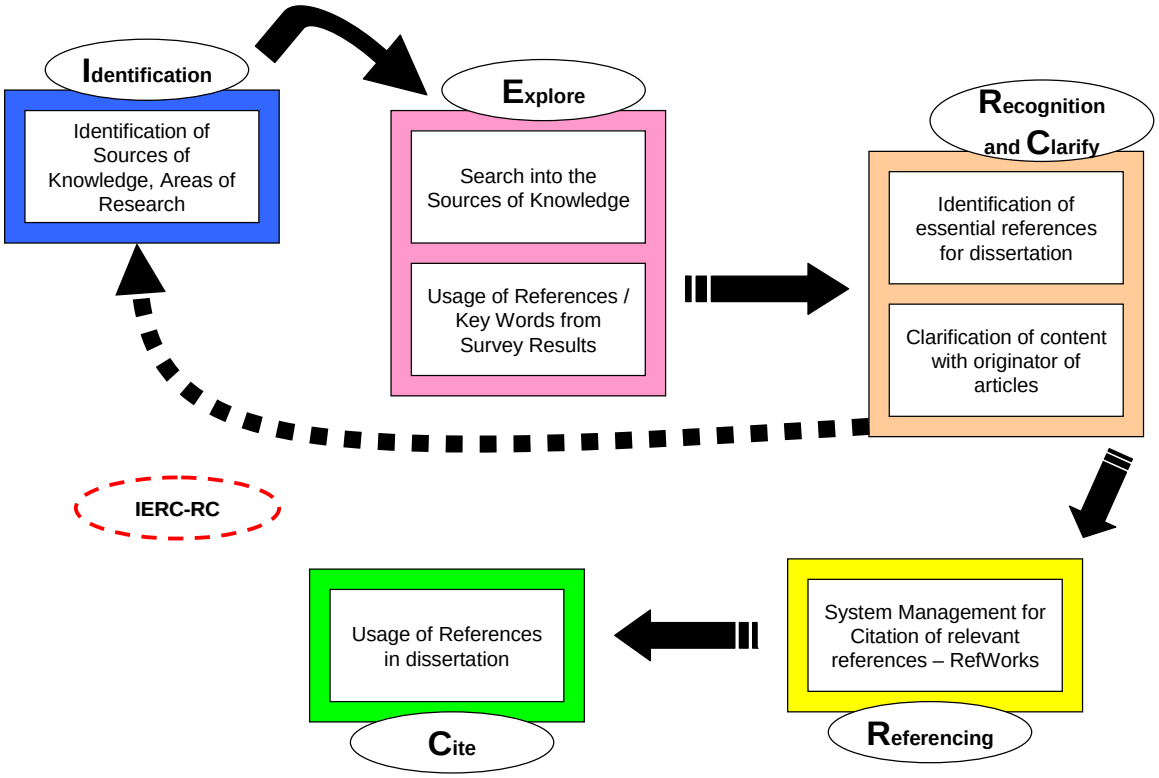
Identification
Identification of Sources of Knowledge, Areas of Research
Explore
Search into the Sources of Knowledge
Usage of References / Key Words from Survey Results
Recognition and Clarify
Identification of essential references for dissertation
Clarification of content with originator of articles
IERC-RC
System Management for Citation of relevant references – RefWorks
Referencing
Usage of References in dissertation
Cite

Figure 9 Methodology for Literature Review (IERC-RC)

## B. SUMMARY OF LITERATURE REVIEW

### 1. Meta-Visualizing Tool

The snapshot of the Meta-Visualizing Tool is depicted in Figure 10. This figure shows the relationship of some of the sources of literature review to the topics of consideration for the thesis. This tool allowed relationships to be drawn, thus allowing an understanding of the various topics to each other.

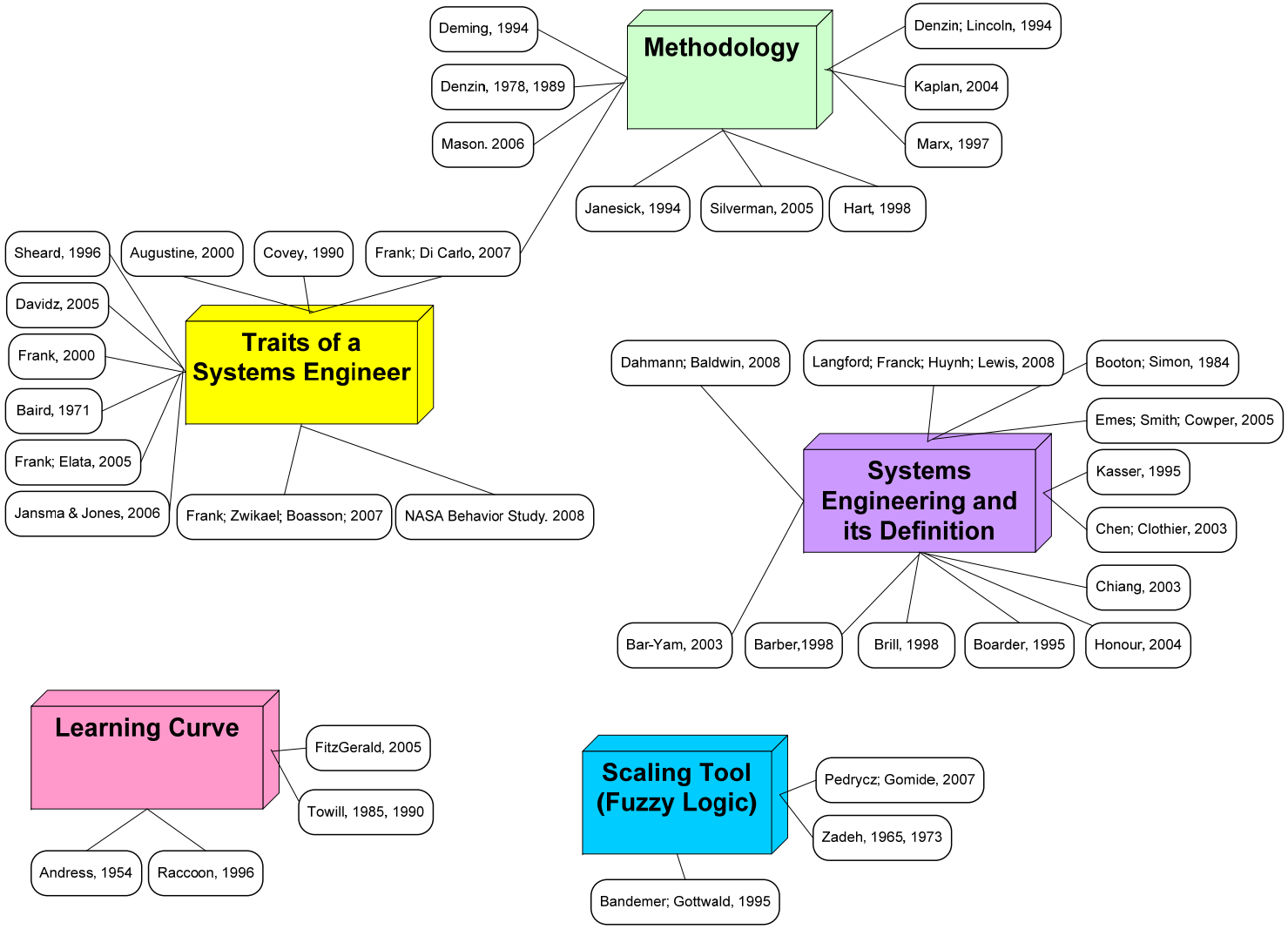


Figure 10 Meta-Visualizing Tool for Literature Review

## C. READINGS

This section looks at the readings that assisted in the classification of the information and the summarization of the following, contained within those readings (modified from Murcott, 1997):

1. What do we know about the topic?
2. What will the thesis say critically about what is already known?
3. Has anyone done anything related to the thesis?
4. Where does the thesis fit in with what has been done before and how is it beneficial?

### 1. Traits of Systems Engineers

As previously mentioned, there has been, over time, a compilation of many articles and books that cover the traits of successful Systems Engineers. The ability of a Systems Engineer to think systemically was seen to be an essential trait, as covered extensively by Baird (1971); Frank, Zwikael and Boasson (1997); Frank (2000); Augustine (2000); Frank and Elata (2005) and Davidz (2005). Sheard (1996) conducted further research on the twelve possible roles of a Systems Engineer. There were some variations where attempts were made to look at specialized Systems Engineers, e.g., in Space Systems by Moore (2000). Frank, Frampton and Di Carlo (2007) conducted comparison studies between a Systems Engineer and Systems and IT Architects. These identified traits foster an understanding as to what could possibly make a good Systems Engineer. As mentioned previously, a triangular comparison (Figure 11) was done of those traits acquired from the literature reviews, those required by today's companies in the classified ads and those given in surveys by practicing Systems Engineers. It was noted that many of the traits were common to all three sets of gathered data.

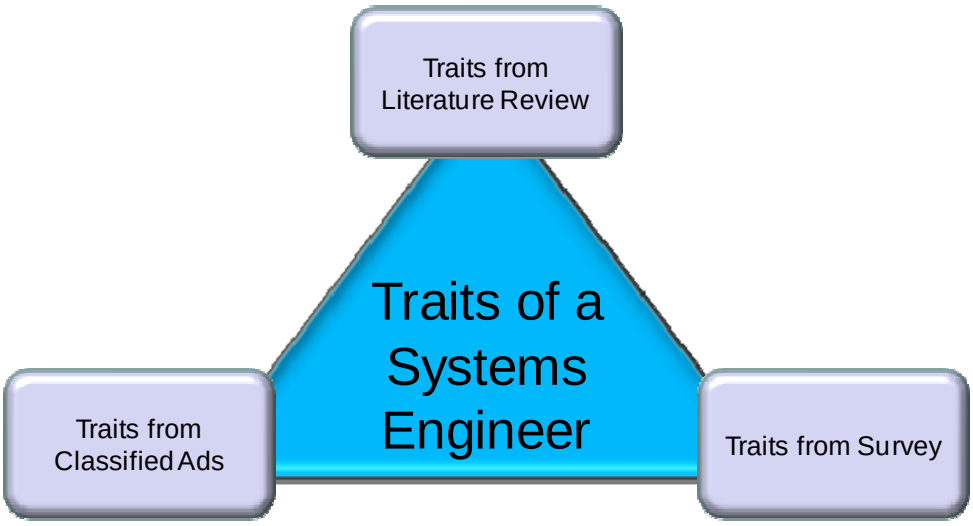


Figure 11 Triangular Comparison

With the great body of research done on the required and desired traits, the question lies in the relationship of time to the acquirement of these traits in order to be a good Systems Engineer.

## 2. Systems Engineering and Its Definition

In his paper to the Proceedings of the 17th International Symposium of the INCOSE, San Diego, CA., 2007, Kasser mentioned that:

> Research has shown that one reason for the lack of agreement (of the activities, roles and definition) is that systems engineers do many and different tasks in their work and consequently have different perspectives on Systems Engineering. In addition performing Systems Engineering seems to be like solving wicked problems.

Systems Engineering is a discipline that requires interdisciplinary knowledge in order for a practicioner to be of value to the project at hand. There are many different permutations today that define what Systems Engineering is all about. Appendix A covers a search for the various definitions of Systems Engineering, apart from the definition offered by the International Council of

Systems Engineering (INCOSE) (2006). The teaching of Systems Engineering is said to have started in 1950 (Brill, 1998). A comparison was made of the various definitions of Systems Engineering over the years, since it was first taught in the 1950s; this is depicted in Figure 12, Figure 13Figure 14. Figure 15 shows the origins of the definitions.

From Figure 12, Figure 13Figure 14 and Figure 15, there is an array of phrases that can be used to define Systems Engineering. In almost all the cases, readers are all too familiar with the functions that are involved in Systems Engineering and thus can relate to these phrases. In this thesis, the following definition of Systems Engineering is used:

Systems Engineering is

a profession,

a philosophy and

a discipline

that adopts an iterative and parallel problem identification and solutioning process, coupled with a collaborative and integrated multi-disciplinary approach.

It involves the life-cycle view of deriving functional solutions to the identified problems of the whole system and its dependants.

The end state is in the satisfaction of the requirements, timeline and budget by the stakeholders.

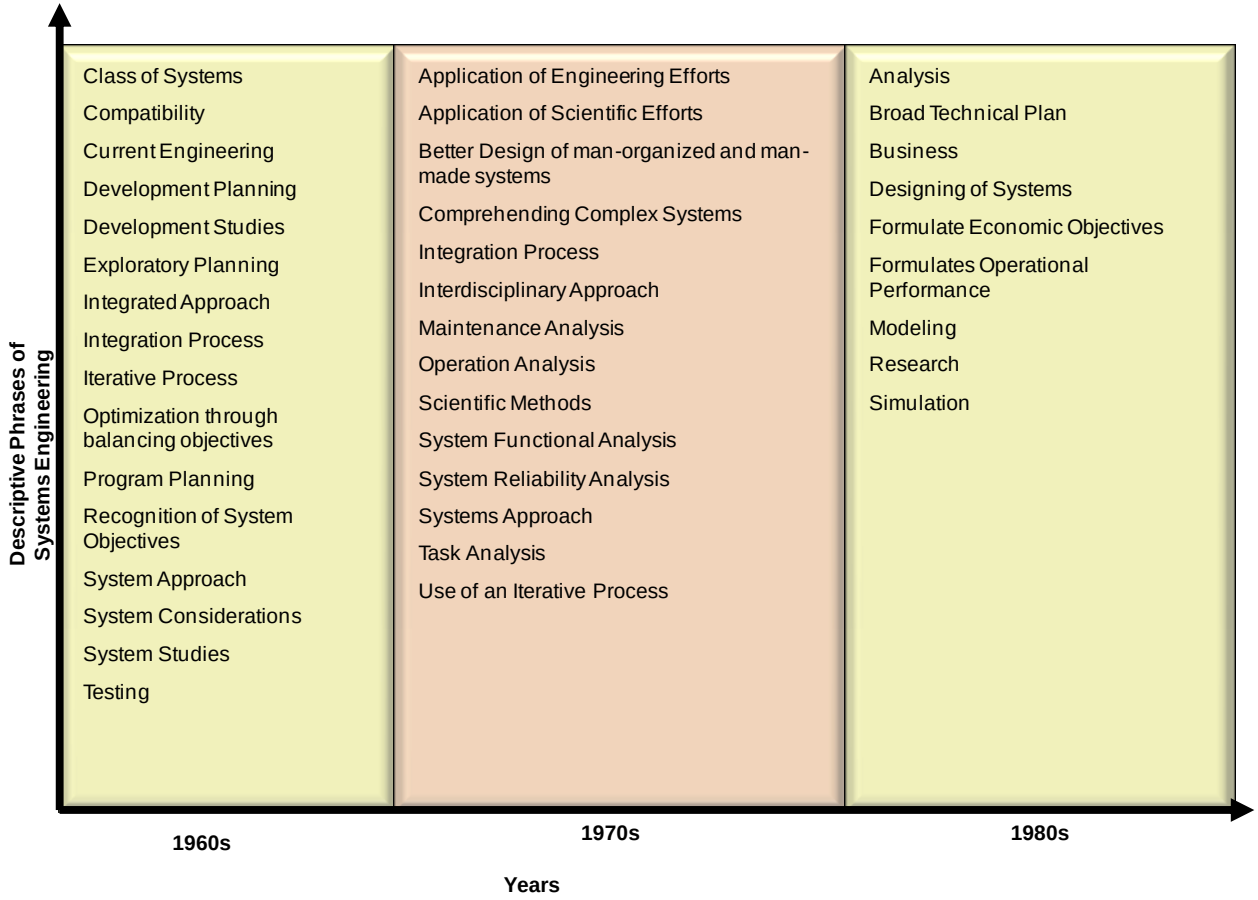


Figure 12 (A) Definition of Systems Engineering Over the Years

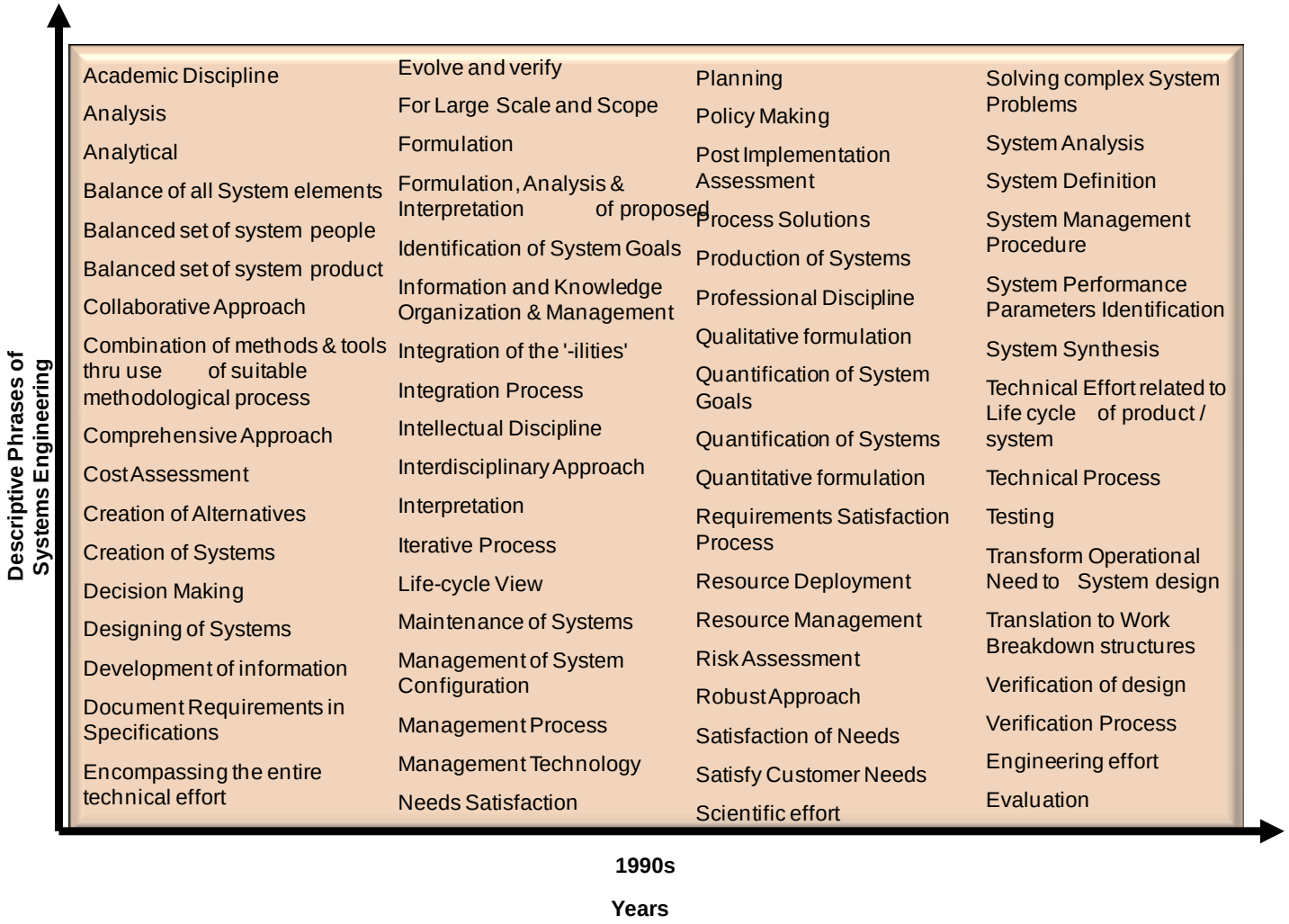


Figure 13 (B) Definition of Systems Engineering Over the Years

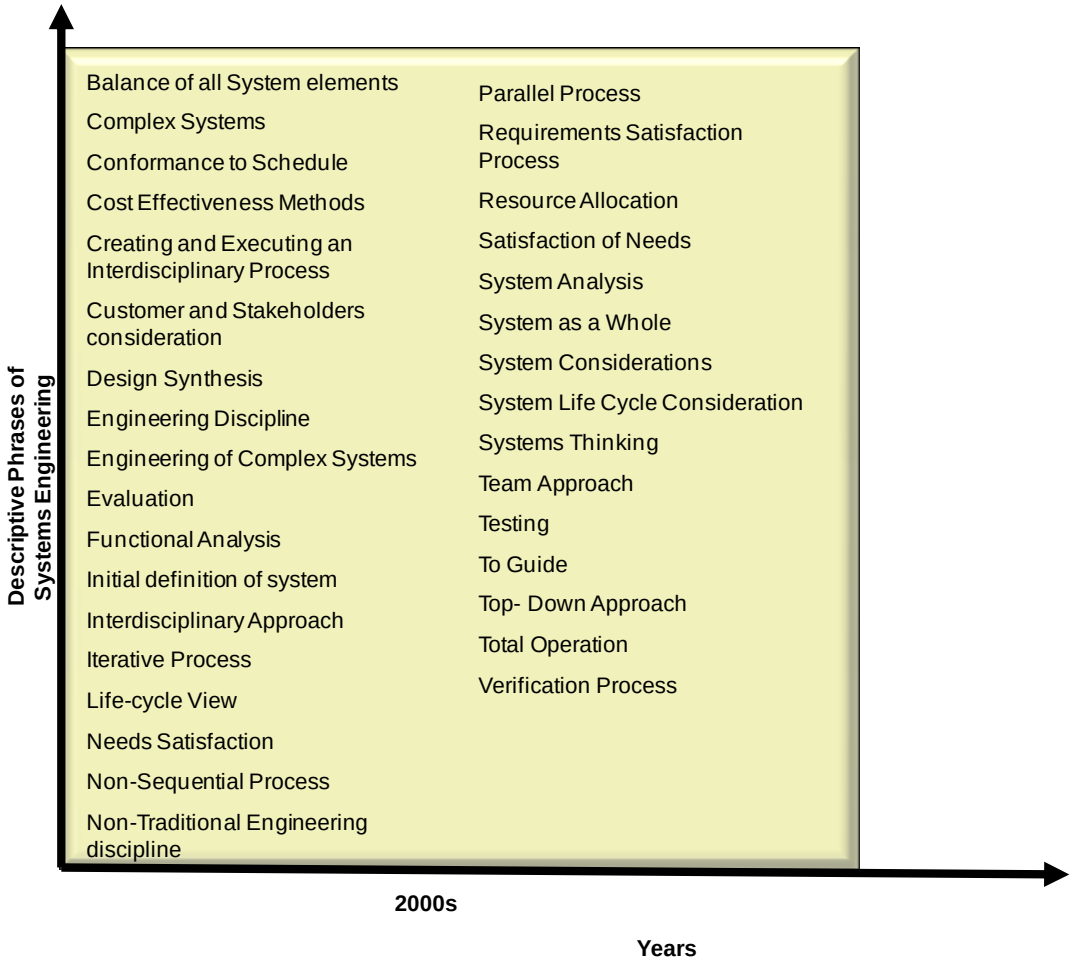


Figure 14 (C) Definition of Systems Engineering Over the Years

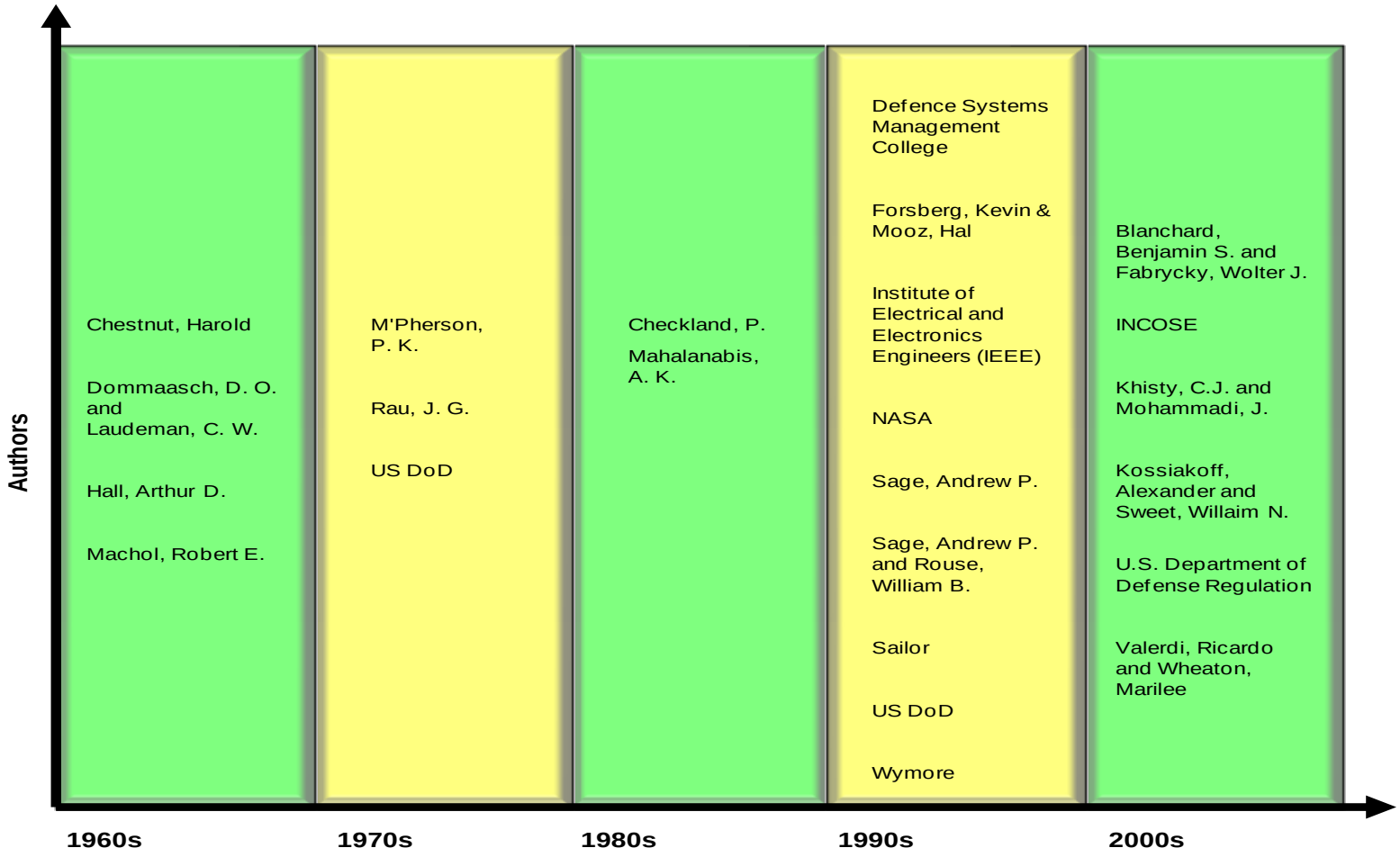


Figure 15 Authors of Cited Definitions of Systems Engineering Over the Years

## 3. Methodology

In the Data Gathering Methodology, the chosen approach was to do a survey of practicing Systems Engineers, text mining of classified ads for Systems Engineers and review of journals, articles and books.

The survey of practicing Systems Engineers allowed the thesis to be initiated in two ways. First, it allowed the data gathering phase to be initiated (i.e. the gathering of the traits that make a good Systems Engineer). Next, the survey allowed for the initial categorization of traits in order to acquire the traits from the classified ads and the literature review.

The acquired data from the identified sources had to be in the natural state of existence for the application of the modified text-mining. The natural state of existence here refers to the absence of any possible biasness, i.e. skewedness in survey questions, propaganda in classified ads, etc. Hence, acquiring data from the classified ads and from the literature review was deemed to be in the natural state, as is it taken that there are no ‘interference’ in the contained information.

In the Analysis of Data, the chosen method had to include a measurement scale to add some degree of measurement to the quantitative traits gathered. For this, Fuzzy Logic was chosen.

### a. Data Gathering Method

Data Gathering involved a series of processes as depicted in Figure 16. The sources of the data being gathered, i.e., literature review, surveys and classified ads, had to be representative of the population being studied, i.e., the Systems Engineering community. As with any sociological study, it was obvious that there could be resident errors in the survey results if the process were not managed from the start. Some of the inherent errors in the survey, modified from the list of thirteen sources of survey errors originally outlined by Demming (1994) in Denzin (1989), are shown in Table 5:

Table 5 Possible sources of error in surveys

| S/N | Possible Error Source in Survey | Implication(s) | Rectification |
|---|---|---|---|
| 1 | Variability in the response | The variability in the responses would mean that there is no 'standard' traits list that is agreed by all on what makes a good Systems Engineer | Variability in the responses is expected in the survey as the respondents would have different levels of experience as well as operating from a different level of Systems Engineering (Kasser and Massie, 2001). For this, the thesis will take into account all the offered traits and not discard any outliers to prevent misrepresentation |
| 2 | Biasness arising from an unrepresentative selection of respondents | There could be some traits not being highlighted for a specific industry | In the selection of the practicing Systems Engineers to be surveyed, effort will be taken to ensure different industries are within the sampled population |

| S/N | Possible Error Source in Survey | Implication(s) | Rectification |
|---|---|---|---|
| 3 | Errors in coding, processing, editing, and tabulation | This will be directly related to the modified text-mining activity. These errors will evolve into either the stressing or diminishing of the importance of certain traits. Also, certain traits might be passed off a "ad hocing"[8] | Effort will be made to ensure that if the traits given require rephrasing, their meanings will be as close as possible to the phrases in the database. However, this is a potential source of inherent error. To reduce the possibility of ad hocing, all traits will be considered and none discarded |
| 4 | Errors in the interpretation of the survey question by respondents (misunderstanding, personal bias) | The results collected cannot be used as it will not synergize with the data of traits | Clarification replies to the respondents will be sent to verify the replies if the questions were misinterpreted. However, this is a potential source of inherent error |
| 5 | Differences in the form of survey (face-to-face interviews, telephone interview, mail) | Different survey climates will produce differences in the detail of responses, leading to a variation in the data. However, the effects of these differences are not known (Denzin, 1989; Demming, 1994) | The survey will be standardized in the form of emails, to reduce any possible sources of errors |

[8] Ad Hoc'ing is a term used in Denkin (1989) from Garfinkel (1967) that describes the tendency to allow a response to be coded as an instance of a category, i.e., 'act as if' the response can be categorized in that manner.'

There are a variety of sampling strategies available for use (e.g., Theoretical Sampling,[9] Illustrative Sampling,[10] and Triangulation.

The selection of the sampling strategy required the strategy to be as representative as possible of the Systems Engineering community. This needs to be from a theoretical and realistic (real world) point of view. Otherwise, the traits gathered will not be representative of the community.

Triangulation is one of the sampling strategy alternatives to validate the gathered data (Denzin and Lincoln, 1994). Triangulation is seen to be the answer to the dilemma of whether a specific source in the data will be robust enough to provide the conclusions of the thesis. Hence, the *combination of multiple methods, empirical materials, perspective and observers in a single study is best understood as a strategy that adds rigor, breadth, and depth to any investigation* (Denzin and Lincoln, 1994; Flick, 1992).

Triangulation can be understood from four definitions (Denzin, 1978): Data,[11] Investigator,[12] Theory[13] and Methodological[14] Triangulation; a fifth fifth was offered by Janesick (1994): Interdisciplinary[15] Triangulation.

[9] Selecting groups or categories to study on the basis of their relevance to the research question and theoretical position (Mason, 2006).

[10] Relationship between sampled contexts and phenomenon and the population of interest is illustrative/evocative in nature. This approach seeks only to provide a 'flavor' to the population (Mason, 2006).

[11] Use of a variety of data sources in a study (Denzin and Lincoln, 1994; Janesick, 1994).

[12] Use of several different researchers or evaluators (Denzin and Lincoln, 1994; Janesick, 1994).

[13] Use of multiple perspectives to interpret a single set of data (Denzin and Lincoln, 1994; Janesick, 1994).

[14] Use of multiple methods to study a single problem (Denzin and Lincoln, 1994; Janesick, 1994).

[15] Consideration of other disciplines to study a single problem (Denzin and Lincoln, 1994; Janesick, 1994).

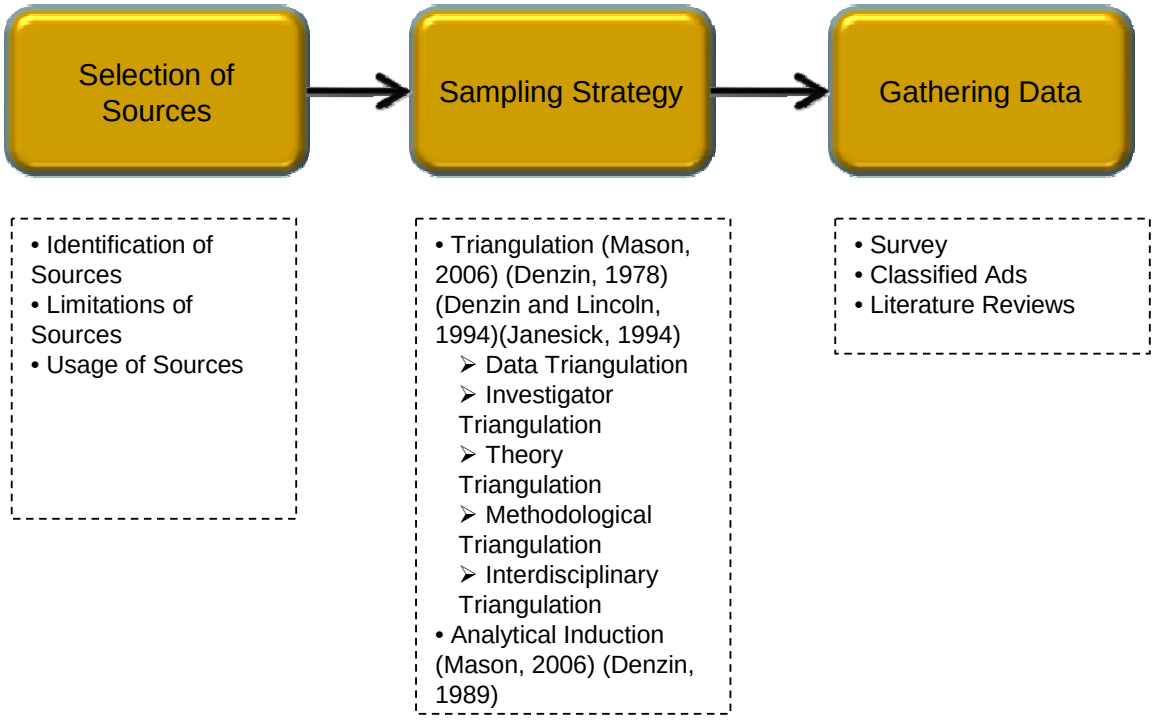


Figure 16 Data Gathering Process

In the study reviewed by Frank, Frampton and Di Carlo (2007), a 'termination of the collection of data' method mentioned by Silverman (2000), was adopted. The method articulates the establishment of categories (outstanding repeated elements) on the analysis of raw data. As such, for this thesis the data sample number is largely determined by the 'establishment' of these categories.

A 'modified' meta analysis[16] methodology was adopted in the decision for the source of the data. The 'modification' here relates to the absence of statistical methods to analyze the data, while data from several sources was analyzed to draw conclusions. Multiple sources were used in order to reduce any

[16] Meta Analysis refers to the analysis of the results of several studies for the purpose of drawing conclusions (Kaplan, 2004, p. 281).

possible bias associated with a single source. For this case, a survey of practicing Systems Engineers, text mining of classified ads for Systems Engineers and review of journals, articles and books were carried out.

### b. Analysis of Data

As mentioned, a 'modified' meta analysis methodology was used to analyze data from several sources. The adopted methodology omitted the use of statistical equations for measurements. In this case, the error of effect size associated with most meta analysis studies need not be considered.

> Text mining tries to solve the crisis of information overload by combining techniques from data mining, machine learning, natural language processing, information retrieval, and knowledge management. (Feldman and Sanger, 2006)

Data mining deals with structured databases of facts (Hearst, 2003). The goal in text mining is also to uncover unknown information (trends, patterns) within the set of naturally occurring text.

In this thesis, the conventional text mining process was modified by not using any automated system in the pattern recognition of the naturally occurring text gathered. The possible effect of this would be ad hocing (i.e., categorization) of the traits.

Based upon the literature review (includes queries to authors and experts) carried out on text mining, there has been no study carried out on the traits of a profession. The categories formed from the mined text will clarify the traits of a good Systems Engineer.

## 4. Fuzzy Logic

The last (but not least) category researched as part of the literature review was a process to quantify these traits, while establishing a relationship among them.

Hipparchus used a six-point brightness scale in 150 B.C. as a means for relative comparison of star magnitude. Similarly, social scientists use a variety of scales in order to provide a means of measurement of every conceivable social-psychological impression (Lodge, 1981). With these instances in mind, the thesis looked at possible scaling of the traits gathered.

The original idea behind fuzzy logic, as advanced by Zedah in the mid-1960s, was to initiate and propagate the transition from traditional mathematical modeling in engineering to a new, much more qualitative, 'rough' modeling using fuzzy sets and fuzzy methods (Bandemer and Gottwald, 1995). Fuzzy Sets were defined by Zedah (1965):

> A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership (characteristic) function which assigns to each object a grade of membership ranging from zero and one…

Fuzzy sets offer an important and unique feature of describing information granules whose contributing elements may belong to varying degrees of membership (belongingness) (Pedrycz and Gomide, 2007).

Today, fuzzy logic has made its way into many applications in common use, from home appliances to automobiles and software.

This thesis has embraced aspects of the class of objects (Categories), grades (Scaling Factors), and membership (relationship between categories) to produce a series of Fuzzy Logic scales.

# III. TRAITS FINDINGS

## A. SURVEY

### 1. Overview of Survey Conducted

An approval was obtained from the Naval Postgraduate School (NPS) Institutional Review Board (IRB) to conduct a survey on the traits that make a good Systems Engineer. The approval form is contained in Appendix B.

A survey was conducted of 33 practicing Systems Engineers for their opinions as to what makes a good Systems Engineer. Most of those surveyed had more than seven years of experience. The survey was conducted via email and the responses tabulated to derive naturally occurring categories. Once these categories were formed, the survey ceased. The number of respondents acquired was sufficient to garner the categories for the traits.

### 2. Approach Taken for Survey

The end state of the survey was to establish a set of categories with the traits that make a good Systems Engineer. This required that those being surveyed have some form of experience as Systems Engineers and that they be 'been-there, done-that' kinds of persons, creating a creditable list of traits. The process for the survey is depicted in Figure 17.

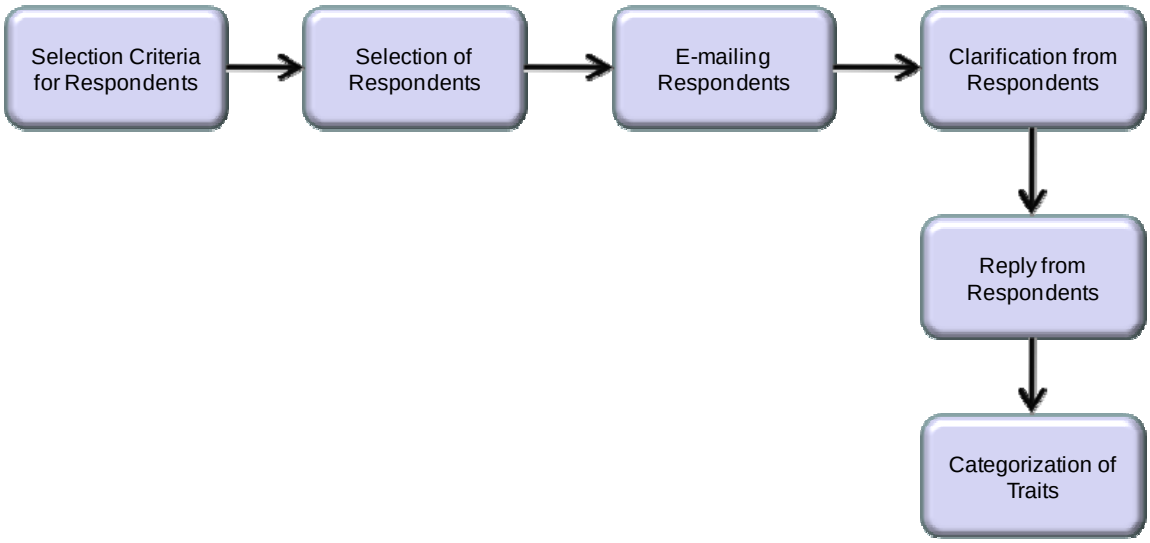


Figure 17 Process Flow for Survey

## B. CLASSIFIED ADS

### 1. Overview

The classified ads were used as a source of traits for a Systems Engineer. These ads were confined to those available on the Internet. Forty classified ads were used in this case.

### 2. Approach Taken

There are hundreds of classified ads that can be used for extracting the traits required for a Systems Engineer. This thesis limited the ads to only those available on the Internet. From Silverman (2000), the sample size used was determined when categories of these traits naturally formed. Figure 18 shows a nearly identical process flow of acquiring the traits of a Systems Engineer from classified ads:

The question tackled in this area of research was:

*What are the traits that successful companies/organizations look for in their employment of a Systems Engineer?*

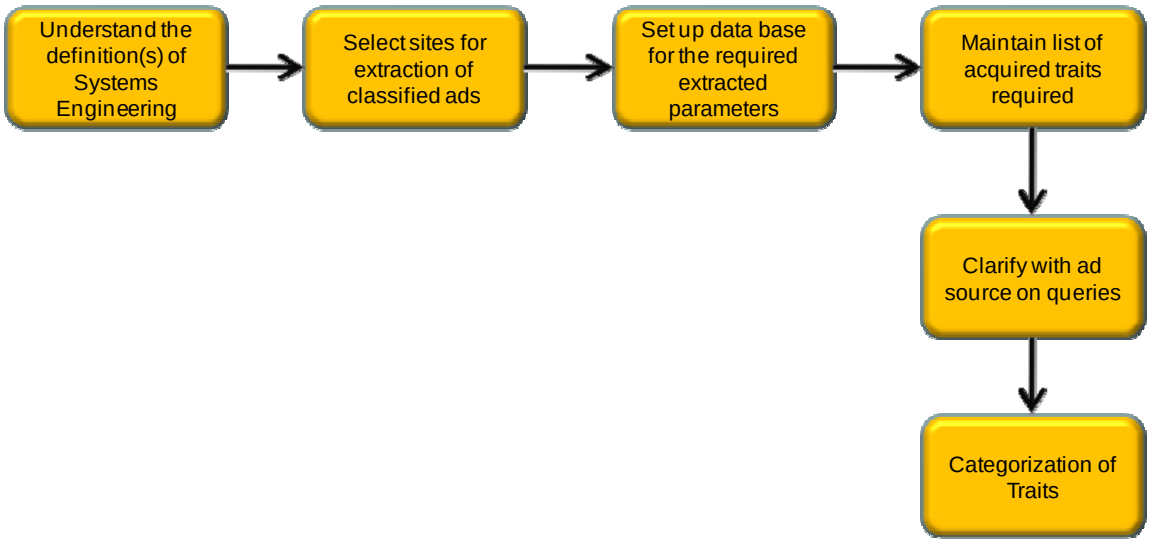
Understand the definition(s) of Systems Engineering
Select sites for extraction of classified ads
Set up data base for the required extracted parameters
Maintain list of acquired traits required
Clarify with ad source on queries
Categorization of Traits

Figure 18 Process Flow for Extracting Traits from Classified Ads

## C. LITERATURE REVIEW

### 1. Overview

The literature review was done to determine the taxonomy of traits that have been investigated by other authors. The search for these recommended traits spanned the various sources of knowledge, as depicted in Figure 19

### 2. Approach Taken

The literature review for the traits of a Systems Engineer was confined to the sources of knowledge reviewed. Some of the sources were recommended by the practicing Systems Engineers surveyed. Figure 19 outlines the process used:

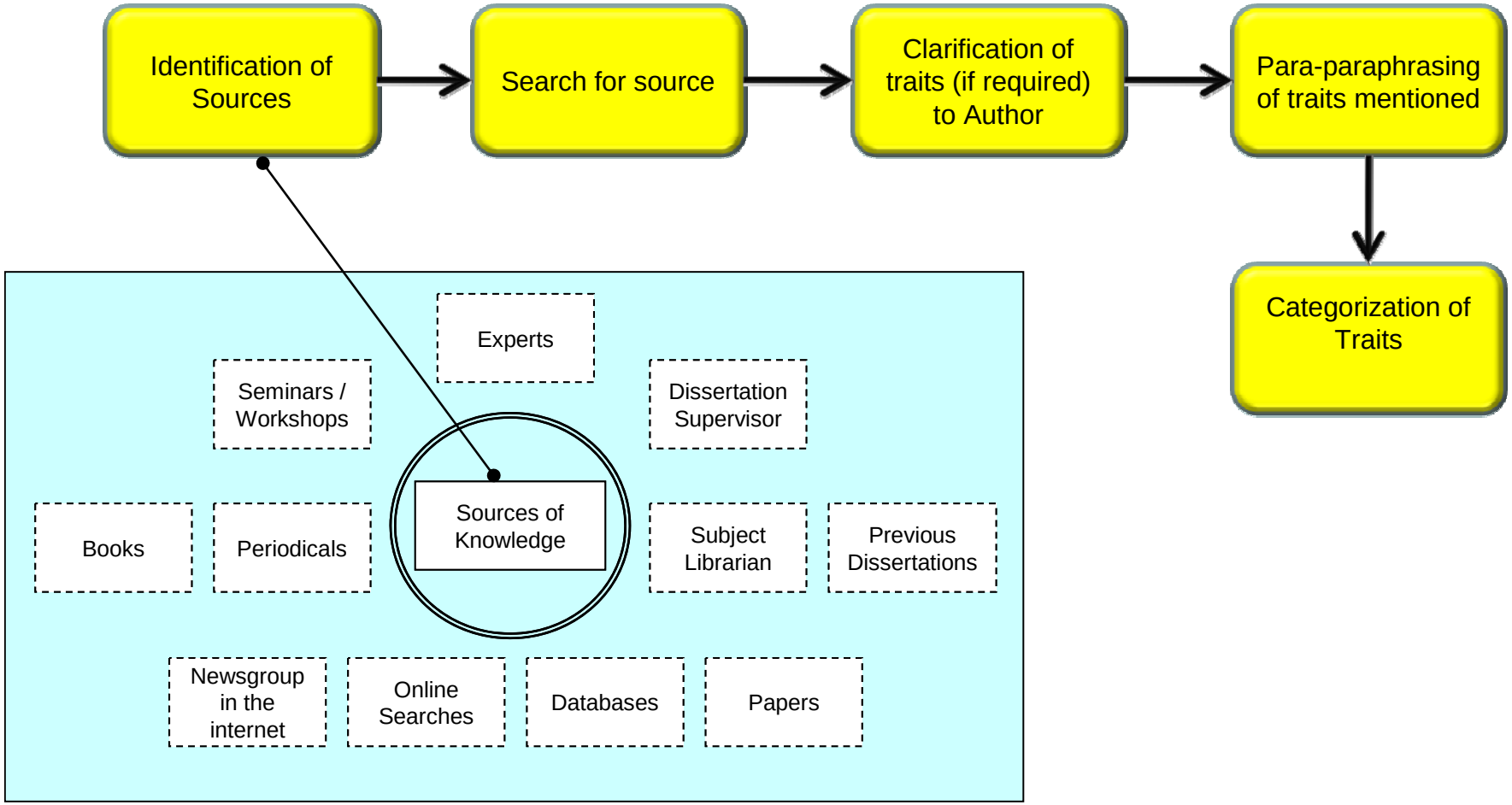


Figure 19 Process Flow for Traits Literature Review

## D. SUMMARY

### 1. Survey

The survey uncovered some interesting results as to the traits that make up a good Systems Engineer. More than 50% of the respondents agreed that **Oral and Written communication skills** were trademarks of a good Systems Engineer. Understanding the current Systems Engineering tools and having the ability to apply the knowledge at the System Level with interdisciplinary knowledge are also required. Figure 20 summarizes the counts of the specific traits of a good Systems Engineer mentioned in the collected data.

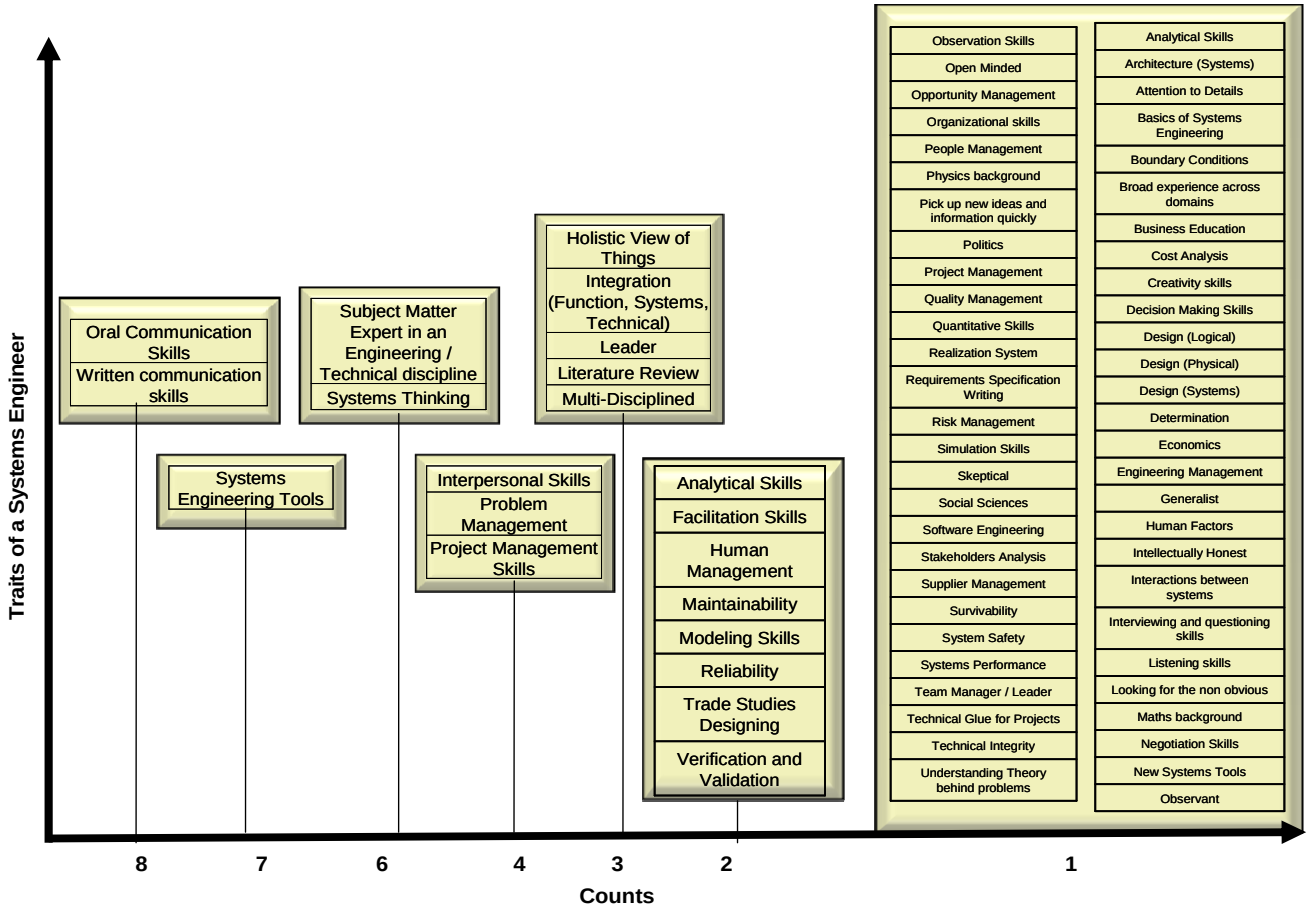


Figure 20 Summary of Traits (Survey)

### 2. Classified Ads

A Fuzzy Logic Scale was created to summarize the traits desired by employers. The scale was designed in accordance with the number of years of experience and was scaled from 1 to 10, with 1 being the least experienced and 10 being the most experienced.

At all levels of experience, employers desire Systems Engineers to possess good oral and written communications skills, coupled with the ability to be a team player. It is also noticed that beyond specific levels of experience, certain traits are desired. For example, for values of 3 and above on the fuzzy scale of experience, Interpersonal Skills, Analytical Skills, Systems Thinking and many other characteristics are sought in a Systems Engineer.

### 3. Literature Review

The literature review for the traits of a Systems Engineer saw insignificant changes from the 1960s to today. Figure 21 and Figure 22 (pages 50 and 51 respectively) outline the summary of these traits:

## E. MERGING OF RESULTS

### 1. Baseline for Merging

The three sources (Classified Ads, Survey, Literature Review) for the traits of a Systems Engineer were merged using the key questions of:

*What makes a good (successful) Systems Engineer?*

*What are the desired traits of a good Systems Engineer?*

### 2. Essential Traits

Over 700 traits were gathered from the three sources mentioned. An amalgamation of the sources of the traits was done and the counts for each particular trait received were used as the axis for the comparison. A fuzzy scale was then created to have a high scale for high counts, and a low scale for low

counts. This is shown in Figure 25 (page 54). The traits were grouped to have a member relationship to the scale of the level of experience.

To eliminate any possible bias in the classified ads fuzzy logic experiential scale, an amalgamated list of traits obtained from the literature review and survey was compared against the classified ads fuzzy logic experiential scale. This is shown in Figure 23 (page 52).

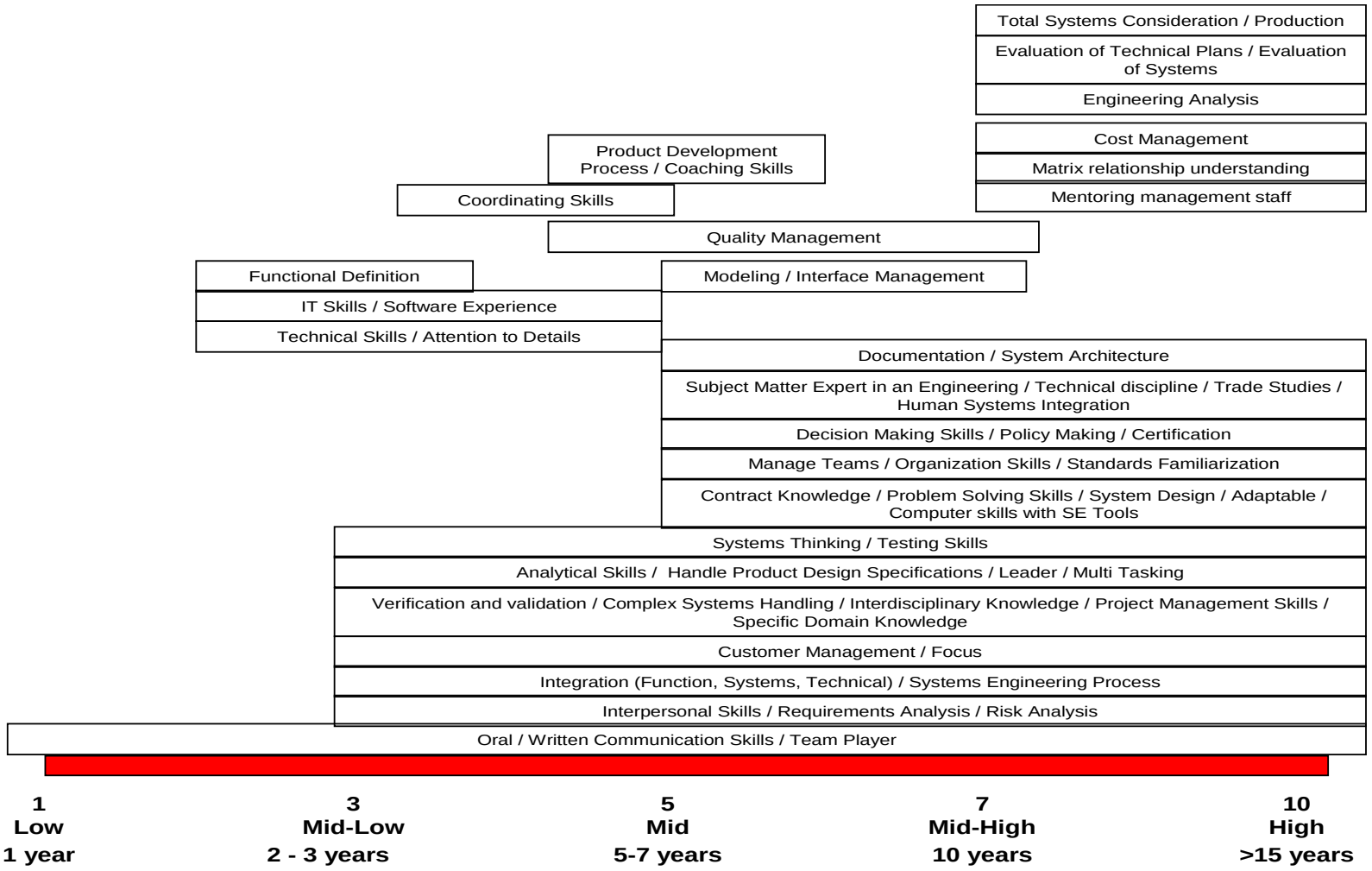
Total Systems Consideration / Production
Evaluation of Technical Plans / Evaluation of Systems
Engineering Analysis
Cost Management
Matrix relationship understanding
Mentoring management staff
Product Development Process / Coaching Skills
Coordinating Skills
Quality Management
Functional Definition
Modeling / Interface Management
IT Skills / Software Experience
Technical Skills / Attention to Details
Documentation / System Architecture
Subject Matter Expert in an Engineering / Technical discipline / Trade Studies / Human Systems Integration
Decision Making Skills / Policy Making / Certification
Manage Teams / Organization Skills / Standards Familiarization
Contract Knowledge / Problem Solving Skills / System Design / Adaptable / Computer skills with SE Tools
Systems Thinking / Testing Skills
Analytical Skills / Handle Product Design Specifications / Leader / Multi Tasking
Verification and validation / Complex Systems Handling / Interdisciplinary Knowledge / Project Management Skills / Specific Domain Knowledge
Customer Management / Focus
Integration (Function, Systems, Technical) / Systems Engineering Process
Interpersonal Skills / Requirements Analysis / Risk Analysis
Oral / Written Communication Skills / Team Player
1 Low 1 year
3 Mid-Low 2 - 3 years
5 Mid 5-7 years
7 Mid-High 10 years
10 High >15 years

Figure 21 Fuzzy Logic of Traits to Years of Experience (Classified Ads)

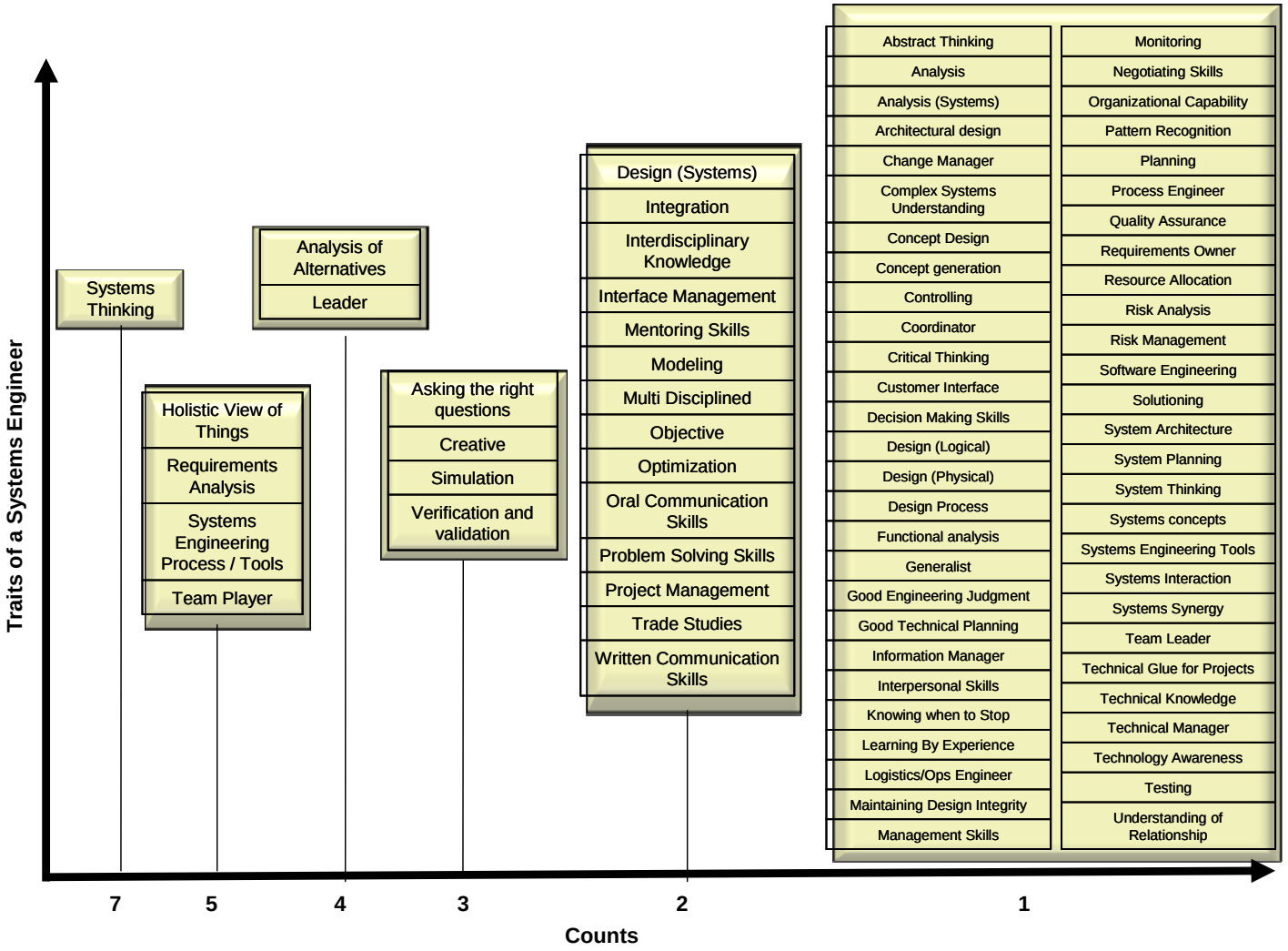


Figure 22 Summary of Traits by Count (Literature Review)

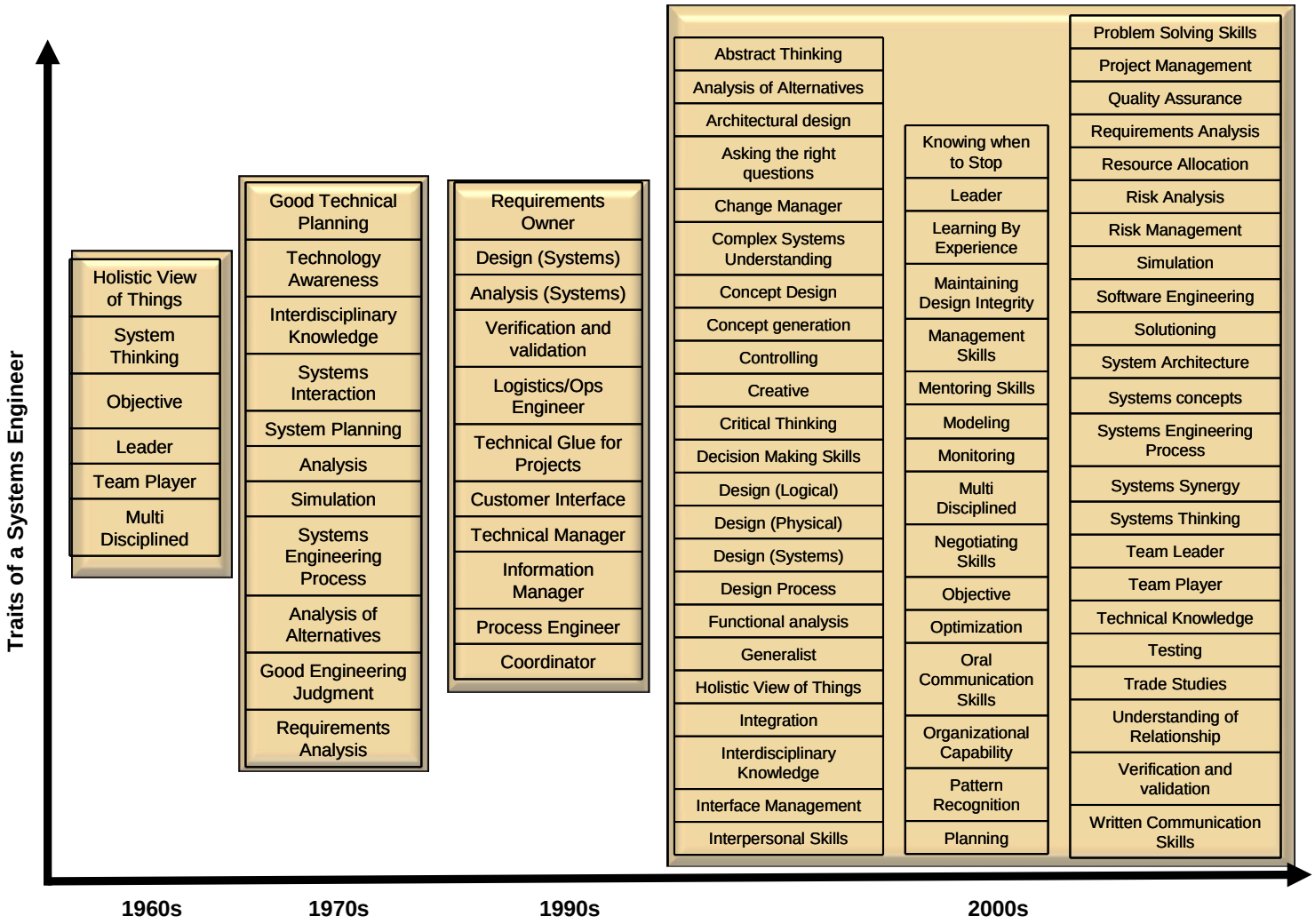


Figure 23 Summary of Traits by Year of Publication (Literature Review)

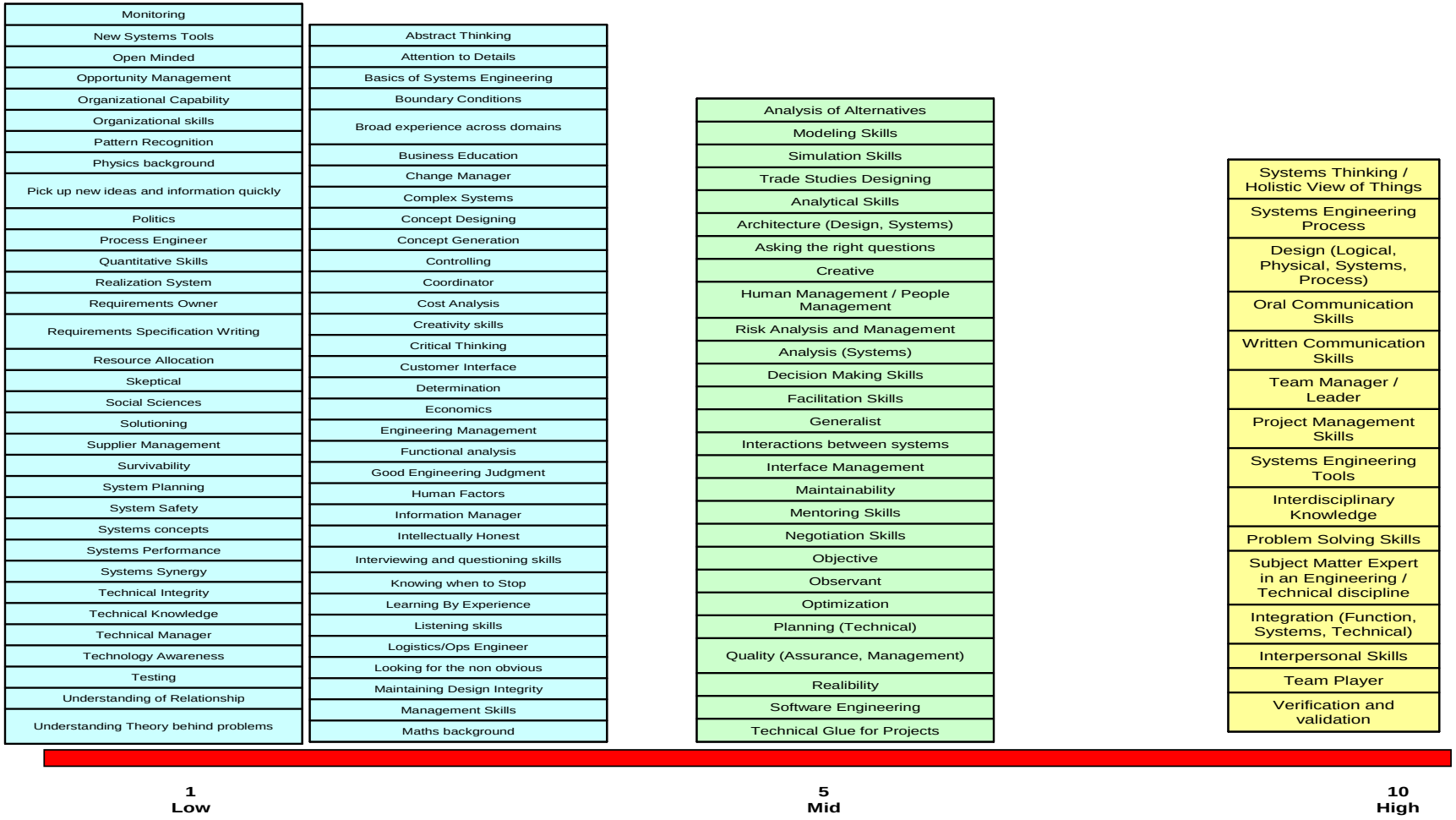


Figure 24 Fuzzy Scale of Amalgamated List (Survey and Literature Review)

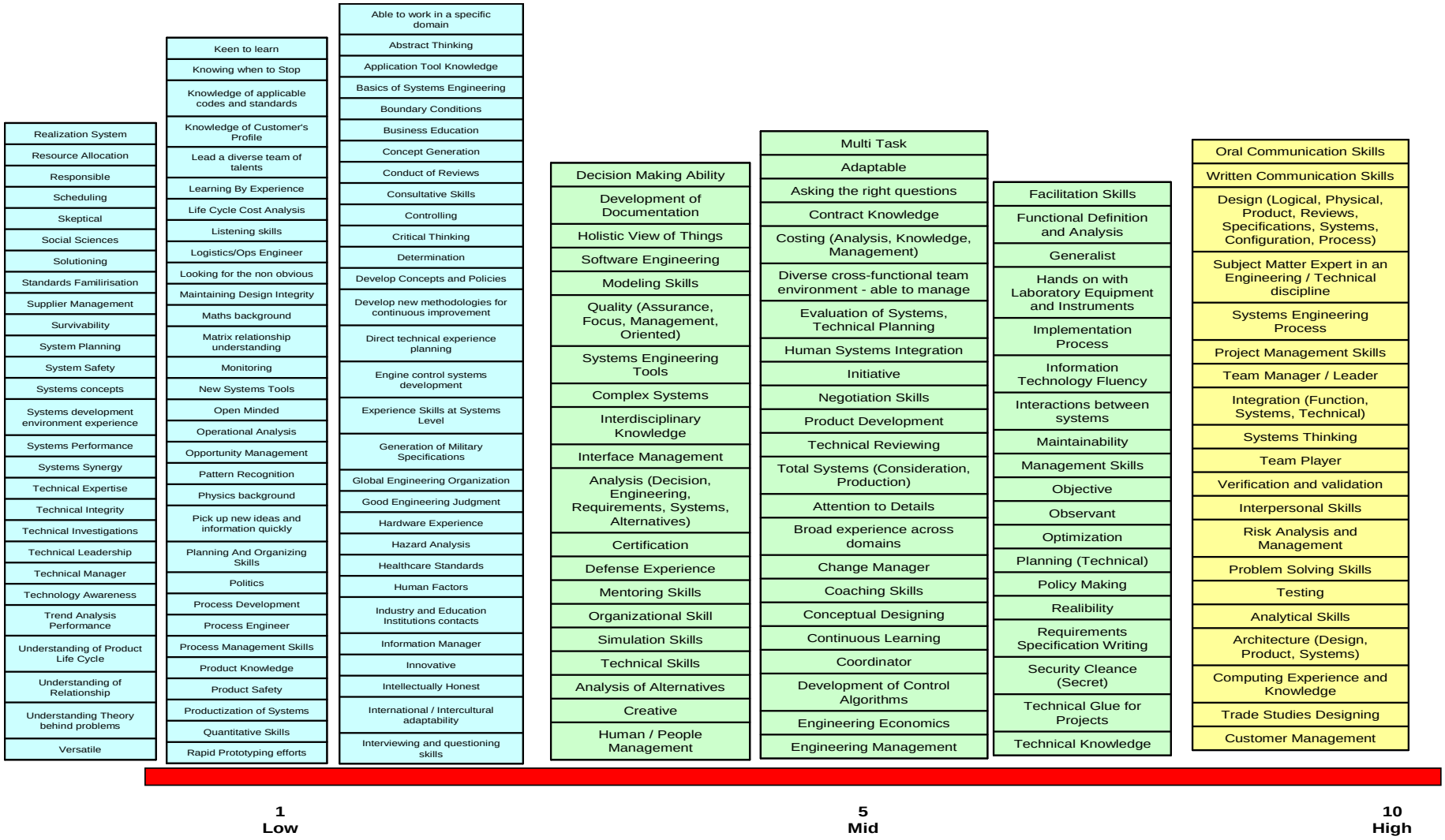


Figure 25 Fuzzy Scale of Amalgamated List (Survey, Classified Ads and Literature Review)

# IV. FUZZY LOGIC OF TRAITS OF A SYSTEMS ENGINEER

*Can a model be used to understand the essential traits required from the list of varied traits?*

*How large is the gap that exists between a novice and expert Systems Engineer?*

## A. TYPES OF SCALES

### 1. Experiential Scale

The fuzzy logic scale for the experience of a Systems Engineer takes into account industry requirements as manifested in the classified ads. The number of years of experience mentioned was pegged to the required traits in the classified ads. With these, a fuzzy scale was created with the number of years of experience being scaled from 1 to 10, 1 denoting a low experience level and 10 the most experienced Systems Engineer. Figure 27 shows the experiential fuzzy logic scale developed. Within the scale, an adaptation of Moore's (2000)[17] definitions of Fat-Short[18] and Thin-Tall[19] Systems Engineers was used to describe the different types of Systems Engineers.

The characteristic nature of the scale showed the following:

#### a. Years of Experience

The experience level could be broken into specific number of years, as depicted in the classified ads. These ranges are shown as Scale 1 (1 year), Scale 3 (2-3 years), Scale 5 (5-7 years), Scale 7 (10 years), and Scale 10 (more than 15 years).

---

[17] The term was originally used by Mead and Conway (1979) to describe tall-thin designers.

[18] Fat-Short – person with a specialized set of technical skills who cannot easily integrate concepts from multi-disciplines.

[19] Thin-Tall – person with a broad technical skill who can easily integrate concepts from multi-disciplines.

### b. Categories of Traits

From the fuzzy scale, it was noted that certain traits were expected at each scale level. On the other hand, Oral and Written communication skills and the ability to be a team player were desired traits regardless of individual experience level. These categories can be seen as an acknowledgement that certain traits found beyond Scale 5 (5-7 years) take time to develop within the Systems Engineer.

### c. Membership

Within the experiential fuzzy logic scale, there is a member relationship of the groups of traits to the fuzzy scale. For instance, cost management, total systems consideration, mentoring and engineering analysis have a relationship to a scale of 7 to 10 on the experience scale. This gives rise to generic membership input-output statements such as, IF INPUT is HIGH EXPERIENCE, OUTPUT is cost management, total systems consideration, mentoring and engineering analysis, where INPUT (1,10). These logic expressions are thus expressed as:

Table 6 Logic expressions of Experience Levels

| S/N | INPUTS | Symbol | Values |
|---|---|---|---|
| 1 | Experienced | E | (7,10) |
| 2 | Mid-experienced | M | (3,6) |
| 3 | Novice | N | (1,2) |

Within the experiential fuzzy logic scale, there is a member relationship of the groups of traits to the fuzzy scale. For instance, cost management, total systems consideration, mentoring and engineering analysis have a relationship to a scale of 7 to 10 on the experience scale. This gives rise

to generic membership input-output statements such as, IF INPUT is HIGH EXPERIENCE, OUTPUT is cost management, total systems consideration, mentoring and engineering analysis, where INPUT (1,10). These logic expressions are thus expressed as:

Table 6, creates a characteristic function as shown in Figure 26:

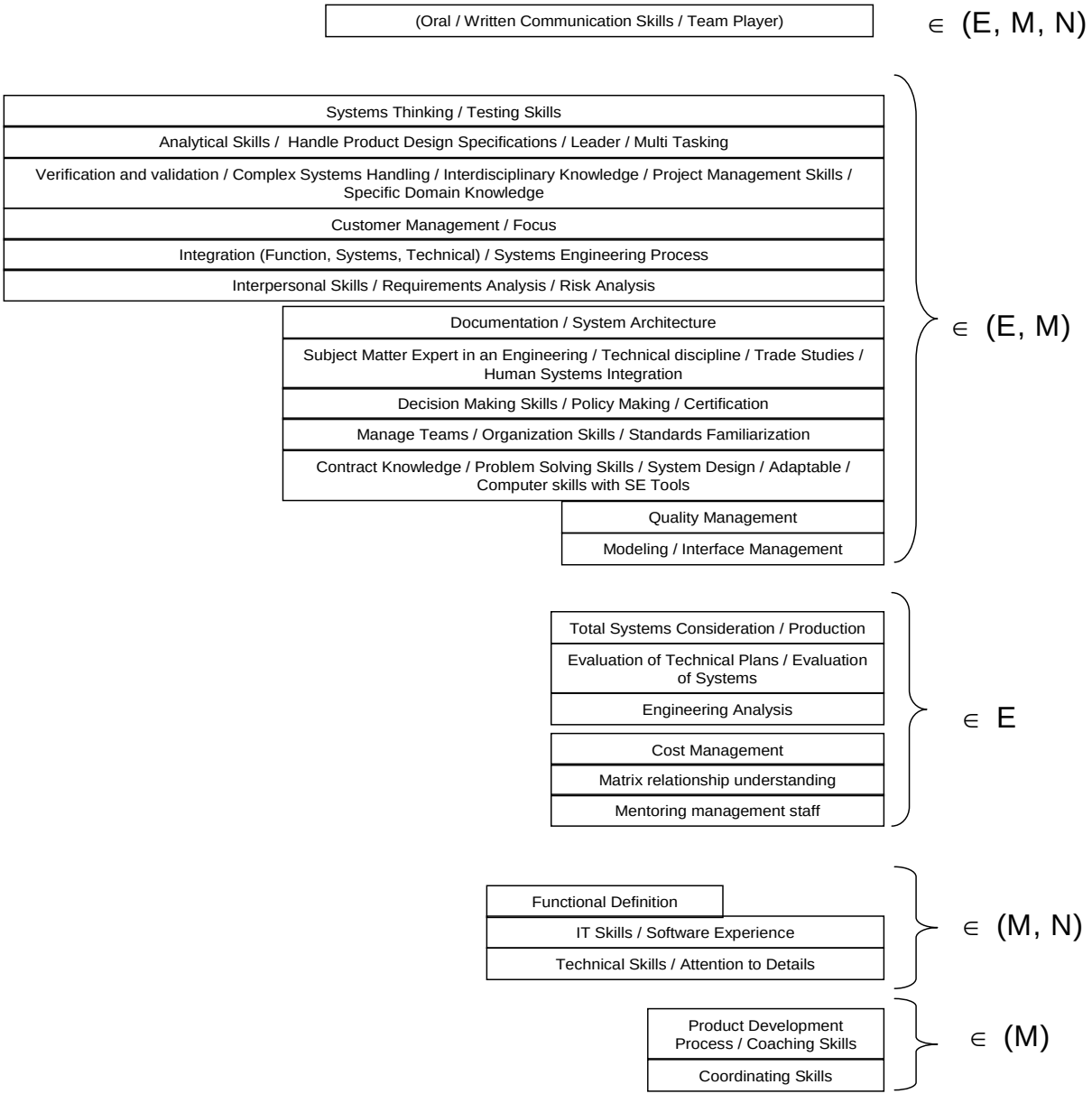
(Oral / Written Communication Skills / Team Player)
∈ (E, M, N)
Systems Thinking / Testing Skills
Analytical Skills / Handle Product Design Specifications / Leader / Multi Tasking
Verification and validation / Complex Systems Handling / Interdisciplinary Knowledge / Project Management Skills / Specific Domain Knowledge
Customer Management / Focus
Integration (Function, Systems, Technical) / Systems Engineering Process
Interpersonal Skills / Requirements Analysis / Risk Analysis
Documentation / System Architecture
Subject Matter Expert in an Engineering / Technical discipline / Trade Studies / Human Systems Integration
Decision Making Skills / Policy Making / Certification
Manage Teams / Organization Skills / Standards Familiarization
Contract Knowledge / Problem Solving Skills / System Design / Adaptable / Computer skills with SE Tools
Quality Management
Modeling / Interface Management
∈ (E, M)
Total Systems Consideration / Production
Evaluation of Technical Plans / Evaluation of Systems
Engineering Analysis
Cost Management
Matrix relationship understanding
Mentoring management staff
∈ E
Functional Definition
IT Skills / Software Experience
Technical Skills / Attention to Details
∈ (M, N)
Product Development Process / Coaching Skills
Coordinating Skills
∈ (M)

Figure 26 Characteristic Functions of the Various Traits

With the characteristic functions developed, a mechanism for pegging the category of the membership of the trait to the various experience levels (E, M and N) can be done. This will allow recruiters to know the level of experienced to be sought when a specific trait is desired.

### 2. Worth of Experience Scale

A worth of experience fuzzy scale is simply the annual salary that a Systems Engineer would receive commensurate with the level of experience. A survey was conducted in 1996 by WholeRoot Economic Research Inc. (30 Oct 2008) on the annual salaries of Systems Engineers, based on the level of experience. The nominal values of these salary ranges were calculated based on the scaling factor (Naval Center for Cost Analysis (NCCA), Jan 2008) obtained in Year 2008 Dollars. Figure 28 shows the fuzzy scale of the annual salaries to the scaled experience level of a Systems Engineer.

Figure 27, used in comparison to Figure 28, validates the observation that Thin-Tall Systems Engineers are paid more due to their experience level.

### 3. Traits Industry Scale

Certain industries might require certain specific and essential traits for their Systems Engineers. As such, an attempt was made to generate a fuzzy scale to depict the scale of the traits required of Systems Engineers in the respective industries that had their classified ads sampled in this thesis.

It was noted that the Research, Defense, and Aerospace industries required a higher Traits Level Scaling Factor from their Systems Engineers (i.e., the more experienced).

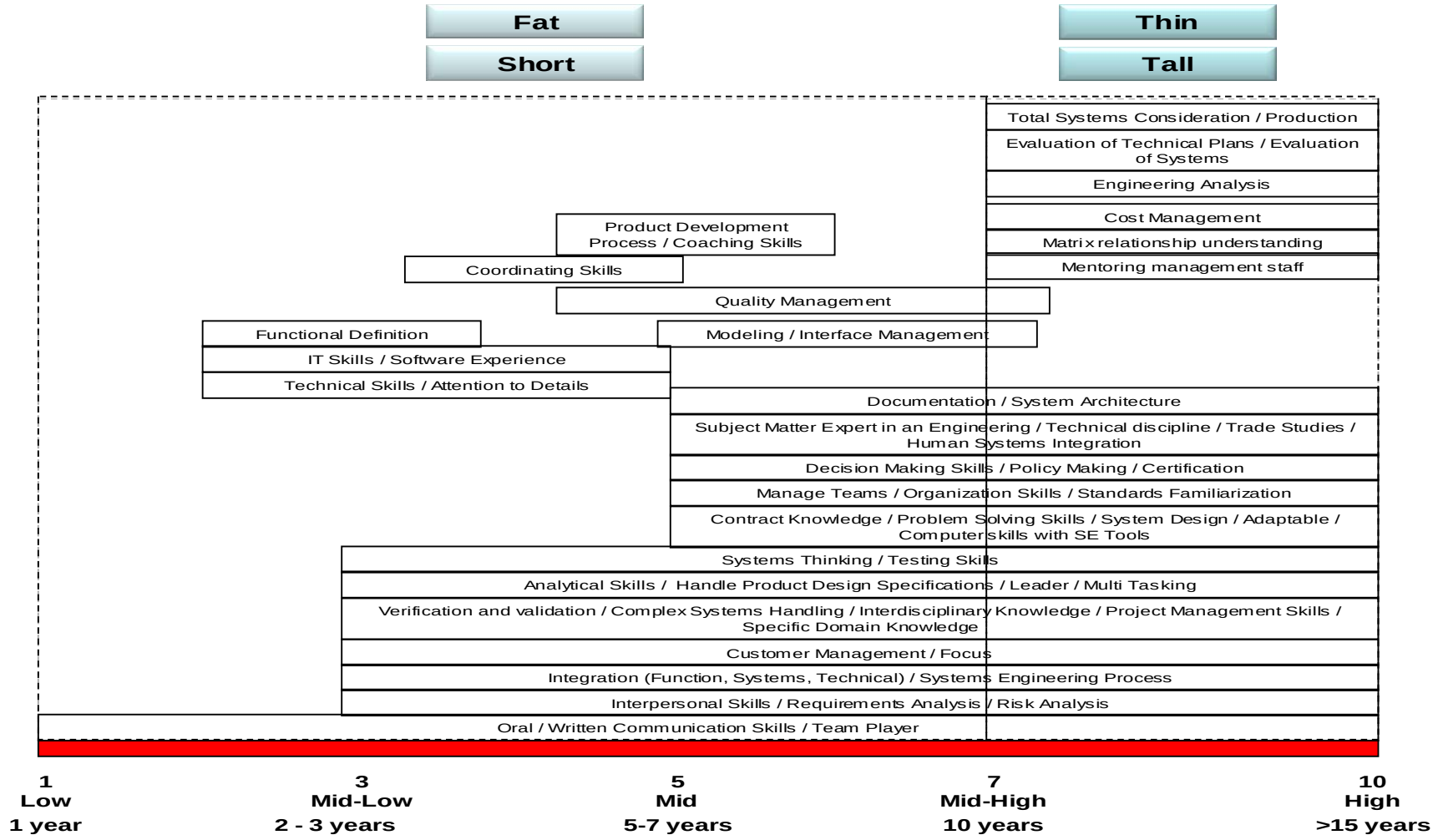
Fat
Short
Thin
Tall
Total Systems Consideration / Production
Evaluation of Technical Plans / Evaluation of Systems
Engineering Analysis
Cost Management
Matrix relationship understanding
Mentoring management staff
Product Development Process / Coaching Skills
Coordinating Skills
Quality Management
Functional Definition
Modeling / Interface Management
IT Skills / Software Experience
Technical Skills / Attention to Details
Documentation / System Architecture
Subject Matter Expert in an Engineering / Technical discipline / Trade Studies / Human Systems Integration
Decision Making Skills / Policy Making / Certification
Manage Teams / Organization Skills / Standards Familiarization
Contract Knowledge / Problem Solving Skills / System Design / Adaptable / Computer skills with SE Tools
Systems Thinking / Testing Skills
Analytical Skills / Handle Product Design Specifications / Leader / Multi Tasking
Verification and validation / Complex Systems Handling / Interdisciplinary Knowledge / Project Management Skills / Specific Domain Knowledge
Customer Management / Focus
Integration (Function, Systems, Technical) / Systems Engineering Process
Interpersonal Skills / Requirements Analysis / Risk Analysis
Oral / Written Communication Skills / Team Player
1
Low
1 year
3
Mid-Low
2 - 3 years
5
Mid
5-7 years
7
Mid-High
10 years
10
High
>15 years

Figure 27 Fuzzy Logic of Traits to Years of Experience (Classified Ads) With Tall-Thin and Short-Fat Categories

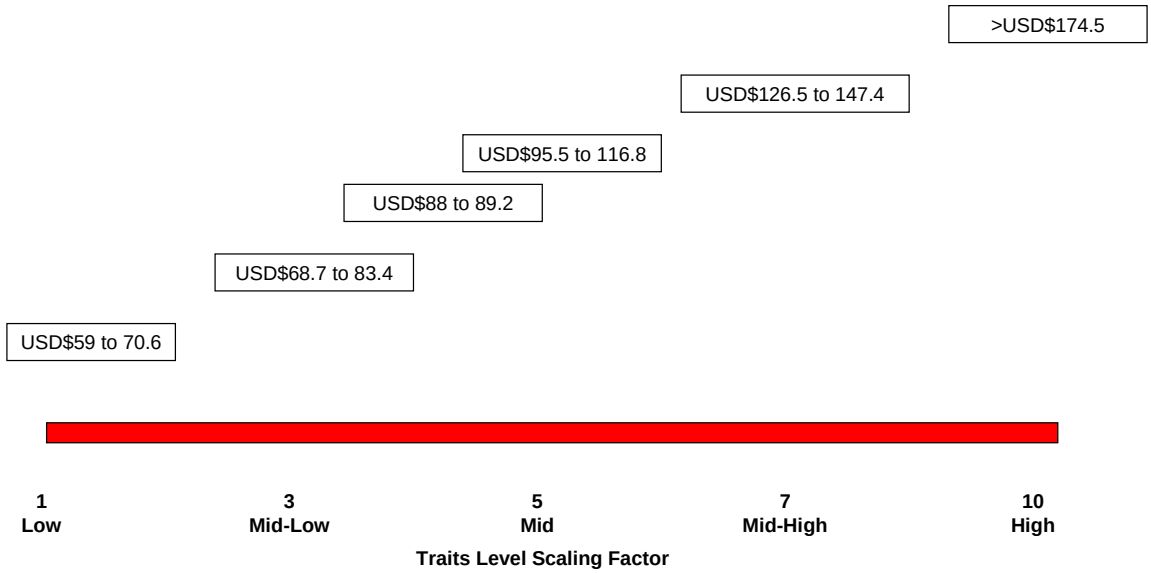


Figure 28 Fuzzy Logic of Annual Salaries to Years of Experience Scale

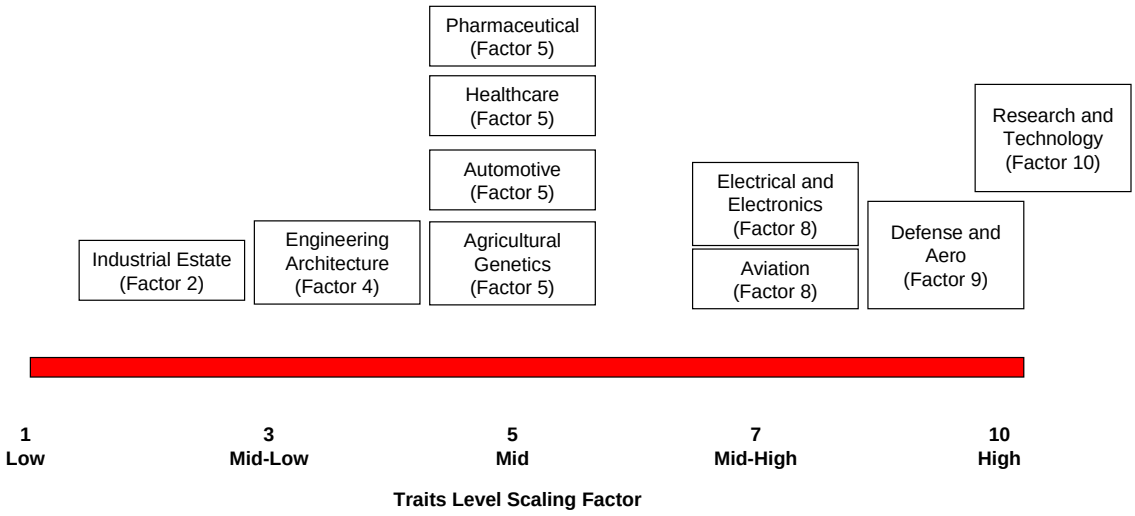


Figure 29 Fuzzy Logic of Industries to Years of Experience Scale

## B. APPLICATIONS OF SCALES

### 1. Academic

A survey on the available Systems Engineering Education was extensively covered by Vidale (1970), touching on education institutions having Bachelor of Science (B.S.), Master of Science (M.S.) and Doctor of Philosophy (Ph.D.) programs. The Experiential Fuzzy Logic Scale could assist academic curriculum drafters to plan and chart the syllabus relevant to industry's requirements. This would better prepare 'learned' Systems Engineers for their expected role(s).

### 2. Industry

The Experiential Fuzzy Scale, with the Worth of Experience Fuzzy Scale, can be adopted as a means to gauge the types of traits that govern the level of experience required in hiring a Systems Engineer, commensurate with the fuzzy scale factor to the annual salary.

With the characteristic functions developed in Figure 26, a mechanism of identifying the category of the membership of the trait to the various experience levels (E, M and N) can be done. This will allow recruiters to know the level of experienced to be sought when a specific trait is desired.

### 3. The Systems Engineer

The Experiential Fuzzy Logic Scale, coupled with studies done by Baird (1971); Frank, Zwikael and Boasson (1997); Frank (2000); Augustine (2000); Frank and Elata (2005); Davidz (2005) and Sheard (1996), would allow a novice Systems Engineer to appreciate the required traits at his given experience level and what is to be acquired in the coming years. As Covey (2004) emphasized in his book on the Seven Habits of Highly Effective People, having the end state in mind keeps one efficient. Thus, by knowing the expected traits that a Systems Engineer needs to acquire at each stage of development, the novice individual would instinctively seek out and acquire the other traits.

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# V. ANALYSIS

## A. FUZZY SCALES

### 1. Industry Requirements of Traits

Comparing Figure 25, the amalgamated traits Fuzzy Scale, to the Experiential Fuzzy Scale in Figure 27 it is seen that most of the high score traits in Figure 25, corresponding to a high count rate in the amalgamated list of traits, are required by industries of a 2-year experienced Systems Engineer. This implies that there is a correlation between the desired traits that make a good Systems Engineer and those required by industries of their Systems Engineers. These traits mentioned, to name a few, include communication skills, design ability, having the knowledge of the Systems Engineering processes, being a team player and leader, having the problem solving skills, systems thinking ability, analytical skills among others.

To eliminate any possible biasness of the classified ads fuzzy logic experiential scale, an amalgamated list of traits obtained from the literature review and survey was compared against the classified ads fuzzy logic experiential scale. It was also observed that the high score traits in Figure 24 are similar to those mentioned in the preceding paragraph. This implies that those traits much desired from academics and practicing Systems Engineers correspond to those required by industry today.

A NASA study on the behaviors of Systems Engineers was completed in October 2008 (Williams and Derro, 2008). An observation was made after the study, involving the survey, interview and observation of 38 of their highly regarded practicing Systems Engineers. The observation was in the reflection of the behaviors being categorized into five broad ‘themes’, namely, leadership, attitudes and attributes, communication, problem solving and systems thinking, and technical acumen. These five observed ‘themes’ correspond as well to the observation made between in the preceding two paragraphs, i.e., there is a

correlation between the desired traits that make a good Systems Engineer and those required by industries of their Systems Engineers, those desired from academics and practicing Systems Engineers.

### 2. Categories of Traits

From the fuzzy scale, it was noted that there were traits expected at different levels of scale. On the other hand, Oral and Written communication skills and “team player” personality were desired traits of a Systems Engineer regardless of the number of years of experience. These categories can be seen as an acknowledgement that certain of these traits found beyond Scale 5 (5-7 years) take time to develop within the Systems Engineer.

## B. ON TIME, ON BUDGET, MEET REQUIREMENTS

### 1. Getting the Traits Right

It was found from Miller (2000, as cited in Honour, 2004) that of 60 Large Engineering Projects (LEP), 18% did not meet budget, 23% did not meet schedule, and 55% did not meet technical objective targets. In relating these to the Experiential Fuzzy Scale in Figure 27 the traits for Requirements Analysis (embedded in Systems Engineering Process), Cost Management, and Project Management Skills can be correlated to Meeting Technical Objective Targets, Budgetary Targets, and Schedule Targets, respectively.

The Experiential Fuzzy Scale in Figure 27 shows that the traits of Project Management and knowledge of Systems Engineering Process (Requirements Analysis) are required from a Systems Engineer as early as the 2-year experience point. The ability to do Cost Management is seen to be required only at the 10-year experience point.

Though there could be many other variables that may have directly and indirectly contributed to the findings from Miller (2000)[20] it is fair to say that having these three highlighted traits could have assisted.

Today's industries are on the right track in seeking Project Management Skills and Knowledge of the Systems Engineering Process as essential requirements for a Systems Engineer at the 2-year mark, in order to reduce the possibility of failures in the Scheduling and Requirements Analysis arena.

## C. RELATIONSHIPS BETWEEN TRAITS, EXPERIENCE LEVEL AND SUCCESS LEVEL IN PROJECTS

### 1. Key to Success in Projects

As seen in the varied definitions of Systems Engineering and in the traits required, Team Work and being able to think in a Multi-disciplined mode is essential to any project. As such, having the correct levels of experience among team members can help to facilitate execution of the project. It was noted that the power and coefficient of the exponential learning curve of a systems engineer Is governed by when a specific trait is employed in a project. Mentioned earlier, it was found from Miller (2000, as cited in Honour, 2004), that of 60 Large Engineering Projects (LEP), 18% did not meet budget, 23% did not meet schedule, and 55% did not meet technical objective targets. In relating these to the Experiential Fuzzy Scale in Figure 27 the traits of a Systems Engineer are mapped to the three elements of determining project success for this thesis ( Table 7): Table 7 Elements in a project to Traits of a Systems Engineer Matching

| S/N | Elements in a Project | Traits of a Systems Engineer (From Figure 21) |
|---|---|---|
| 1 | Satisfying Requirements | Requirements Analysis |
| 2 | Meeting Budgetary Targets | Cost Management |
| 3 | Meeting Schedule(s) | Project Management Skills |

[20] In Miller, 2000, project performance was measured by two sets of variables: (1) Ratings by sponsors of the technical, economic, social, environmental. Political and developmental performance of projects, and (2) Cost and Schedule results.

Honour (2004) further emphasized three impacts to Systems Engineering from the listed findings in Miller (2000).  shows these impacts, mapped to the traits of a Systems Engineer:

Table 8 Impacts to Systems Engineering to Traits of a Systems Engineer Matching

| S/N | Impacts to Systems Engineering | Traits of a Systems Engineer (From Figure 21) |
|---|---|---|
| 1 | The need for a structure of leadership | Leadership |
| 2 | Technical difficulties had no statistically linkage to the overall project performance | Technical Discipline |
| 3 | Technical Excellence is important but not sufficient for a successful project outcome | Technical Discipline |

Learning Curves have significantly matured since the 1970s. Learning Curves have and are still occupying an increasingly important role in a wide range of industries (Towill, 1985). Under mentioned are some statistics on learning (FitzGerald, 2005):

Learn by doing – retain 75% of the information given

Learn by reading materials – retain 10% of read information

Learn by audio [conference] – retain a mere 5%

When it comes to in-house training, a simulated experience is better than no experience at all.  From the retention percentages by FitzGerald (2005), we shall assume that the experts (those with above 15 years of experience) are able to retain 75% of the essential traits listed for a successful project listed in. This assumption is made as it is taken that experts acquire their traits from having been involved in many projects in their career of practicing Systems Engineering. These experts have thus have reached the ‘optimum’ point of having learned the

tricks of the trade, thus being able to contribute all of the 75% that they have retained by doing the job over the years. We further assume that the initial contribution of a novice Systems Engineer to a project, based on the respective listed traits are at 15%. The 15% contribution is initiated at the first instance where the trait appears in Figure 21. Raccoon (1996) covered fifteen forms of the learning equation. The time based approach in acquiring the traits of becoming an expert Systems Engineer is adopted. This is due to the fact that different sets of traits are acquired over the years of experience of performing Systems Engineering. Hence, the exponential learning curve is adopted. Thus, merging the retention percentage by doing from FitzGerald (2005), the essential traits for a successful project from Table 7 and the numeric scales to which these traits are tagged to in Figure 21, some relationships are established.

Figure 30 shows the exponential relationship established between the percentage of contribution of a Systems Engineer (based on the years of experience) to the number of years of experience to a project.

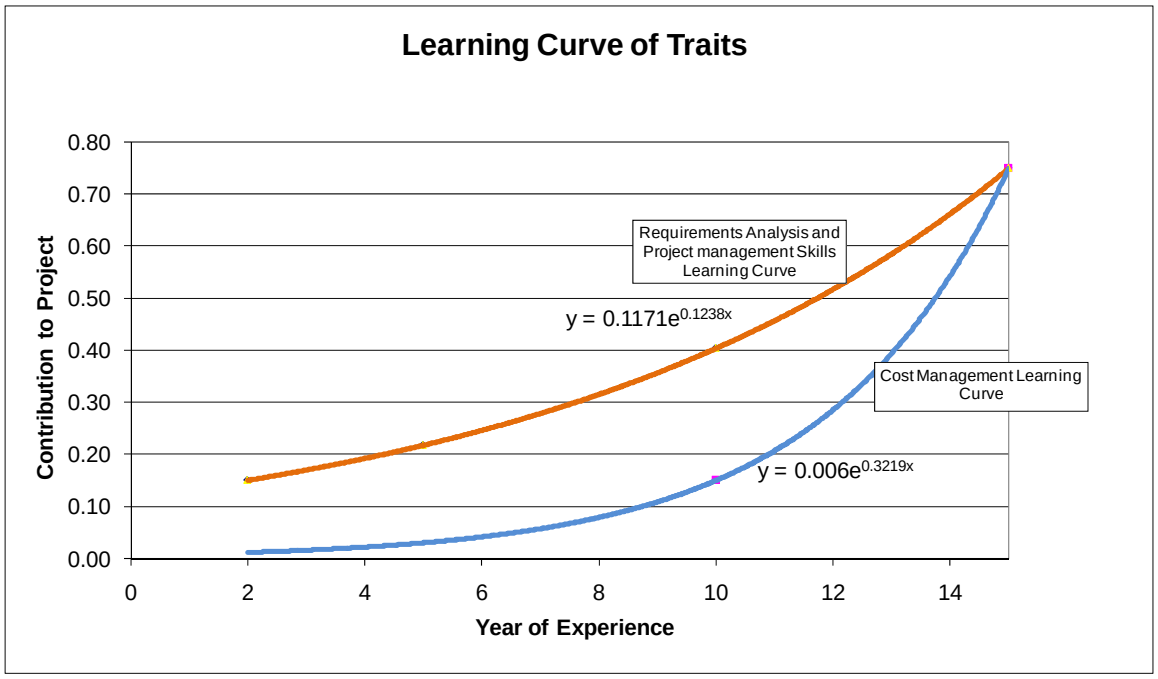


Figure 30 Exponential Relationship between contribution of a Systems Engineer to the number of years of experience

Using the coefficient and power of the exponential learning curves for the requirements analysis, project management skills and cost management, a correlation was established to Figure 21's Experiential Fuzzy Logic scales. There is a direct relationship of the power of the exponential learning curve equation to the Experiential Fuzzy Logic scale. Conversely, there is an indirect relationship of the coefficient of the exponential learning curve equation to the Experiential Fuzzy Logic scale.

From the correlations, we establish the relationship of the power and coefficient of the learning curve exponential equation to the period where the trait is specifically used. For example, the traits of Requirement Analysis and Project Management skills are initiated at the two year point (Figure 21) and for Cost Management, at the ten year point (Figure 21).

The application of this relationship is seen in the appearance of the three traits (Project Management Skills, Cost Management Skills and Requirements Analysis) with the classified ads. Requirements Analysis and Project Management skills are required by recruiters from a two year old System Engineer onwards. As for Cost Management skills, recruiters are only looking at those with ten years of experience to start having this specific trait. Upon extrapolating the learning curve of the Cost Management, it can be seen that if recruiters expect this trait from their two year old System Engineer, the contribution to the project with this trait will be at about 2%. This earlier expectation of the recruiter to the Systems Engineer will allow a gradual build up of the trait rather than a steep learning curve.

# VI. RECOMMENDATIONS

There are some recommendations made from the thesis. This is based upon the traits being desired for in a Systems Engineer and the years of experience of the Systems Engineer.

## A. EXPERIENTIAL FUZZY SCALE

### 1. Recruitment

Figure 26 and Figure 27 represent a tool for recruiters of Systems Engineers to identify the probable characteristic function of the various traits that are required. From the characteristic function, the recruiter can then better indicate the level of experience of the potential candidates.

## B. LEARNING CURVE

### 1. Expected Traits

Learning through experience is exponentially developed. Figure 30 illustrated the relationship between the contribution of a Systems Engineer to the project, in relation to the number of years of experience.

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# VII. CONCLUSION

From the surveys and literature review conducted, it was found that a list of traits was emphasized that make a good Systems Engineer. These included the ability to do systems thinking, a knowledge of the Systems Engineering process, good oral and written communications skills, and having project management skills. These can be found in Figure 24.

The traits desired that of a Systems Engineer by companies and organizations can be found in Figure 21. The traits were segregated into the years of experience of the Systems Engineer. Evidently, there were some traits that were desired regardless of the experience level. These traits include having good oral and written communications skills, the ability to do systems thinking, a leader, analytical skills and being a team player.

A novice Systems Engineer could be honed on the traits that experienced Systems Engineer possess. These include mentoring management staff, being able to do engineering analysis, evaluation of technical plans, and evaluation of systems. The gap is illustrated in Figure 21 in contrast between the traits at the scale rating or 1 and 3 (novice Systems Engineer) against 7 and 10 (experienced Systems Engineer).

The Fuzzy Logic model was adopted with the learning curve to depict the traits of a System Engineer with the years of experience and the growth of some of the traits respectively. It was shown that the Fuzzy Logic scale was able to reference the traits of a Systems Engineer against the years of experience, referencing the annual salaries to the years of experience and the industry's requirements of the traits to the years of experience of the Systems Engineer.

The fuzzy scales developed represent a snapshot of the various traits of a Systems Engineer to the listed variables of income and years of experience. Useful as recruitment tools, the relationship function of a desired traits of a System s Engineer will allow the recruiter some form of indication of the

membership a desired trait has to the years of experience. This shows the relationship between the various traits of a systems engineer to the number of years of experience.

From the analysis, and that of the October 2008 NASA study on the behaviors of Systems Engineers, the study's observation correspond to the thesis' analysis that is a correlation between the desired traits that make a good Systems Engineer and those required by industries of their Systems Engineers, those desired from academics and practicing Systems Engineers.

Also, from the learning curves developed for three of the traits, as depicted in Figure 30, it is shown that the earlier the traits are expected from a Systems Engineer, the less steep the learning curve will be established.

Ethnomethodological studies analyze the methods on how people (in a social environment) form their commonsense knowledge of the environment (Garfinkel, 1984). Given the setting of a project environment, the Systems Engineer would have to form an understanding towards 'common Systems Engineering sense'. For this, the Systems Engineer would have to adopt the System Engineering processes, with the use of the trained and acquired traits that define a Systems Engineer. This thesis has shown that some of the traits of a Systems Engineer would have to be possessed from the point of entry to the environment.

# VIII. FUTURE EXPLORATIONS

## A. TEXT MINING

### 1. Usage of an Automated Process

Use software to do the text mining part of extracting the traits of a Systems Engineer for a more refined list.

## B. USAGE OF ONE-ORGANIZATION FINDINGS

### 1. NASA and Northrop Grumman

It was understood during the research that NASA and Northrop Grumman were undergoing major restructuring in their respective Systems Engineering Training development. Since their study will only come out early in 2009 or later, it is envisaged that their findings would be beneficial to identify the critical traits of a Systems Engineer.

## C. TRAITS ACCORDING TO INDUSTRIES

### 1. Difference in Traits

From Figure 29, it is noted that certain industries might require a unique blend of traits from their Systems Engineers, in accordance with their levels of experience. To reduce possible bias of the data, more samples could be obtained from a different list of industries. In this, the different requirements (traits) and levels of experience of all the Systems Engineers required could be tabulated to further verify the distinct need for a difference in the level of experience in each industry.

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# APPENDIX A. SYSTEMS ENGINEERING DEFINITIONS

Table 9 Systems Engineering Definitions

| S/N | Source | Nature of Source | Author | Year | Definition of Systems Engineering |
|---|---|---|---|---|---|
| 1 | Systems engineering principles and practice | Book | Kossiakoff, Alexander and Sweet, Willaim N. | 2003 | The function of systems engineering is to guide the engineering of complex systems. Systems engineering is focused on the system as a whole-it emphasizes its total operation.<br>To guide - "to lead, manage, or direct, usually based on the superior experience in pursuing a given course," "to show the way." This characterization emphasizes the process of selecting the path for others to follow from among many possible courses-a primary function of systems engineering.<br>System - "a set of interrelated components working together toward some common objective." Implies a multiplicity of interacting parts that collectively perform a significant function.<br>Complex - restricts this definition to systems in which the elements are diverse and have intricate relationships with one another.<br>The function of Systems Engineering is to guide (Lead, manage, direct), the engineering of complex systems. Systems Engineering is focused on the system as a whole - ot emphasizes its total operation. It looks at the system from the outside, that is, at its interactions with the other systems and the environment, as well as from the inside. |
| 2 | Fundamentals of systems engineering. With economics, probability and statistics | Book | C.J. Khisty and J. Mohammadi | 2001 | Some see Soft Systems Thinking as part of SE, others draw the distinction between hard SE and Soft Systems Methodology (such as Khisty and Mohammadi [2001]). |

| S/N | Source | Nature of Source | Author | Year | Definition of Systems Engineering |
|---|---|---|---|---|---|
| 3 | Engineering fundamentals in measurements, probability, statistics and dimensions | Book | K.C. Crandall and R.W. Seabloom | 1970 | Some texts stress the importance of economics in general engineering [Crandall and Seabloom, 1970] |
| 4 | Systems thinking, systems practice | Book | P. Checkland | 1981 | One of the earliest recognised practitioners of modern-day SE, Arthur Hall, suggests: “Systems engineering operates in the space between research and business, and assumes the attitudes of both. For those projects which it finds most worthwhile for development, it formulates the operational, performance and economic objectives, and the broad technical plan to be followed” [Checkland, 1981:130]. |
| 5 | Handbook of Systems Engineering and Management | Book | Andrew P. Sage George Mason University and William B. Rouse Enterprise Support Systems | 1999 | Structure - Systems engineering is management technology to assist clients through the formulation, analysis, and interpretation of the impacts of proposed policies, controls, or complete systems upon the need perspectives, institutional perspectives, and value perspectives of stakeholders to issues under consideration.<br><br>Function - Systems engineering is an appropriate combination of the methods and tools of systems engineering, made possible through use of a suitable methodological process and systems management procedures, in a useful process-oriented setting that is appropriate for the resolution of real-world problems, often of large scale and scope.<br><br>Purpose - The purpose of systems engineering is information and knowledge organization and management to assist clients who desire to develop policies for management, direction, control, and regulation activities relative to forecasting, planning, development, production, and operation of total systems to maintain overall quality, integrity, and integration as related to performance, trustworthiness, reliability, availability, and maintainability. |

| S/N | Source | Nature of Source | Author | Year | Definition of Systems Engineering |
|---|---|---|---|---|---|
| 6 | MIL-STD-499A | Military Standard | US DoD | 1974 | Systems engineering is the application of scientific and engineering efforts to• Transform an operational need into a description of system performance parameters and a system configuration through the use of an iterative process of definition, synthesis, analysis, design, test, and evaluation;• Integrate related technical parameters and ensure compatibility of all physical, functional, and program interfaces in a manner that optimizes the total system definition and design;• Integrate reliability, maintainability, safety, survivability, human engineering, and other factors into the total engineering effort to meet cost, schedule, supportability, and technical performance objectives. |
| 7 | MIL-STD-499B | Military Standard | US DoD | 1994 | An interdisciplinary approach encompassing the entire technical effort to evolve and verify an integrated and life-cycle balanced set of system people, product, and process solutions that satisfy customer needs. Systems engineering encompasses:<br>(a) the technical efforts related to the development, manufacturing, verification, deployment, operations support, disposal of, and user training for system products and processes;<br>(b) the definition and management of the system configuration;<br>(c) the translation of the system definition into work breakdown structures; and<br>(d) development of information for management decision making. |

| S/N | Source | Nature of Source | Author | Year | Definition of Systems Engineering |
|---|---|---|---|---|---|
| 8 | International Council of Systems Engineers (INCOSE) http://www.incose.org/practice/fellowsconsensus.aspx | Web Site | INCOSE | downloaded on 27 Aug 08 last updated 02 Oct 2006 | Systems Engineering is an engineering discipline whose responsibility is creating and executing an interdisciplinary process to ensure that the customer and stakeholder's needs are satisfied in a high quality, trustworthy, cost efficient and schedule compliant manner throughout a system's entire lifecycle. This process is usually comprised of the following seven tasks: State the problem, Investigate alternatives, Model the system, Integrate, Launch the system, Assess performance, and Re-evaluate. These functions can be summarized with the acronym SIMILAR: State, Investigate, Model, I ntegrate, Launch, Assess and Re-evaluate. It is important to note that the Systems Engineering Process is not sequential. The functions are performed in a parallel and iterative manner. |
| 9 | NASA Systems engineering handbook(From http://en.wikipedia.org/wiki/Systems_engineering) | Book | NASA | 1995 | Systems engineering is a robust approach to the design, creation, and operation of systems. In simple terms, the approach consists of identification and quantification of system goals, creation of alternative system design concepts, performance of design trades, selection and implementation of the best design, verification that the design is properly built and integrated, and post-implementation assessment of how well the system meets (or met) the goals." |
| 10 | Systems Engineering Methods (From http://en.wikipedia.org/wiki/Systems_engineering) | Book | Harold Chestnut Information Belbce Laboratory Research and Development Center General Electric Company | 1967 | The Systems Engineering method recognizes each system as an integrated whole even though composed of diverse, specialized structures and subfunctions. It further recognizes that any system has a number of objectives and that the balance between to optimize the overall system functions according to the weighted objectives and to achieve maximum compatibility of its parts. |

| S/N | Source | Nature of Source | Author | Year | Definition of Systems Engineering |
|---|---|---|---|---|---|
| 11 | A Methodology For Systems Engineering | Book | Arthur D. Hall pp 8 to 11 | 1962 | Hall [1962] defined systems engineering as a function with five phases: (1) system studies or program planning; (2) exploratory planning, which includes problem definition, selecting objectives, systems synthesis, systems analysis, selecting the best system, and communicating the results; (3) development planning, which repeats phase 2 in more detail; (4) studies during development, which includes the development of parts of the system and the integration and testing of these parts; and (5) current engineering, which is what takes place while the system is operational and being refined. |
| 12 | Systems Engineering Methodology for Interdisciplinary Teams | Book | Wymore | 1976 | Systems Engineering is the professional, intellectual and academic discipline whose primary concerns of which are the analysis and design of large-scale, complex, man / machine systems. |
| 13 | | | Benjamin S. Blanchard and Wolter J. Fabrycky | 2006 | (a) Top-Down approach that views system as a whole<br>(b) A lifecycle orientation that addresses all phases to include system design and development, production and/or construction, distribution, operation, maintenance and support, retirement, phase-out, and dsiposal<br>(c) Initial definition of system requirements<br>(d) Interdisciplinary or team approach throughout the system design and development process to ensure that all design objectives are addressed in an effective and efficient manner<br>(e) Not traditional engineering discipline |

| S/N | Source | Nature of Source | Author | Year | Definition of Systems Engineering |
|---|---|---|---|---|---|
| 14 | Systems Engineering | Book | Andrew P. Sage George Mason University | 1992 | Systems Engineering is a management technology to assist and support policy making, planning, decision making, and associated resource allocation or action deployment. It accomplishes this through quantitive and qualitative formulation, analysis, and interpretation of the impacts of actions of action alternatives with reference to the user's needs, values, and institutional perspective. Key words are Formulation, Analysis and Interpretation. In fact, all of the Systems Engineering can be thought of as consisting of Formulation, Analysis, and Interpretation of the various ingredients at what we call phases in the lifecycle of a system. Systems Engineering is the design, production, and maintenance of trustworthy systems within cost and time constraint. |
| 15 | | | Sailor | 1990 | Both a technical and management process; the technical process is the analytical effort necessary to transform an operational need into a system design of the proper size and configuration and to document requirements in specifications; the management process involves assessing the risk and cost, integrating the engineering specialties and design groups, maintaining configuration control, and continuously auditing the effort to ensure that cost, schedule, and technical performance objectives are satisfied to meet the original operational need. |
| 16 | | | Forsberg, Kevin & Mooz, Hal | 1992 | The application of the system analysis and design process and the integration and verification process to the logical sequence of the technical aspect of the project lifecycle. |
| 17 | Model-Based Systems Engineering | Book | Wymore | 1993 | The intellectual, academic, and professional discipline the primary concern of which is the responsibility to ensure that all requirements for a bioware/hardware/software system are satisfied throughout the lifecycle of the system. |

| S/N | Source | Nature of Source | Author | Year | Definition of Systems Engineering |
|---|---|---|---|---|---|
| 18 | System Theoretic concepts of Systems Engineering - Proceedings of the European meeting, Vienna. 1973 (Advances in cybernetics and Systems Research) | Book | M'Pherson, P. K. | 1973 | the breadth of vision and the unification of concepts afforded by systems science is timely because of the iterdisciplinary framework that it provides both for comprehending the increasing complexity of today's social-ecological problems and for unravelling such problems by the better design of man-organized and man-made systems. |
| 19 | Optimisation and Probability in Systems Engineering | BookVan Nostrand Reinhold Co, New York, 1970 | Rau, J. G. | 1970 | Consists of the application of scientific methods in integrating the definition, design, planning, development, manufacture, and evaluation of systems. It encompass such terms as systems approach, system functional analysis, system reliability analysis, task analysis, maintenance analysis and operation analysis. it is fundamentally concerned with deriving a coherent total system to achieve a stated set of objectives subject to physical, environment, state-of-the art andeconomical constraints. |
| 20 | Introductory Systems Engineering | Book | A. K. Mahalanabis Professor Department of Electrical Engineering Indian Institute of Technology, Delhi, India | 1982 | Systems Engineering is concerned with the problem of analysis and design of systems using general terms. Systems Engineering has to do with Modelling, Analysis, Simulation and Design. |
| 21 | Principles Underlying Systems Engineering | Book Pitman Publishing Corporation, New York | Dommaasch, D. O. and C. W. Laudeman | 1962 | Systems Engineering is used to describe an integrated approach to the synthesis of entire systems designed to perform various tasks in, which is expected to be, the most efficient possible manner. Systems Engineering is used to desctibe an approach which views an entire system of components as an entity rather than simply as an assembly of individual parts. |
| 22 | Systems Engineering Handbook | Book | Robert E. Machol | 1965 | Systems Engineering is concerned with the design of a specific class of systems. |

| S/N | Source | Nature of Source | Author | Year | Definition of Systems Engineering |
|---|---|---|---|---|---|
| 23 | EIA / IS<br>EIA / IS 632 | Commercial Standard | NA | NA | An interdisciplinary approach encompassing the entire technical effort to evolve and verify an integrated and lifecycle balanced set of system people, product, and process solutions that satisfy customer needs. Systems engineering encompasses:<br>(a) the technical efforts related to the development, manufacturing, verification, deployment, operations support, disposal of, and user training for system products and processes;<br>(b) the definition and management of the system configuration;<br>(c) the translation of the system definition into work breakdown structures; and<br>(d) development of information for management decision making. |
| 24 | IEEE 1220 - Standard for Application and Management of the Systems Engineering Process | Standard | Institute of Electrical and Electronics Engineers (IEEE) | 1994 | An interdisciplinary collaborative approach to derive, evolve, and verify a lifecycle balanced system solution which satisfies customer expectations and meets public acceptability.<br><br>From the standard's abstract - The interdisciplinary tasks, which are required throughout a system's lifecycle to transform customer needs, requirements, and constraints into a system solution, are defined. In addition, the requirements for the systems engineering process and its application throughout the product lifecycle are specified. The focus of this standard is on engineering activities necessary to guide product development while ensuring that the product is properly designed to make it affordable to produce, own, operate, maintain, and eventually to dispose of, without undue risk to health or the environment. |

| S/N | Source | Nature of Source | Author | Year | Definition of Systems Engineering |
|---|---|---|---|---|---|
| 25 | Unraveling the Systems Lexicon | Paper presented at the 1996 INCOSE Symposium | Dr Jerome G. Lake | 1996 | Systems Engineering is an interdisciplinary, comprehensive approach to solving complex system problems and satisfying stakeholder requirements. |
| 26 | ANSI/EIA 632 As a Standardized WBS for COSYSMO | Paper presented at the AIAA 5th Aviation, Technology, Integration, and Operations Conference (ATIO) 26 - 28 September 2005, Arlington, Virginia | Ricardo Valerdi Massachusetts Institute of Technology, Cambridge, MA 02139 and Marilee Wheaton The Aerospace Corporation, El Segundo, CA 90245 | 2005 | Systems engineering is concerned with creating and executing an interdisciplinary process to ensure that the customer and stakeholder needs are satisfied in a high quality, trustworthy, cost efficient and schedule compliant manner throughout a system's entire lifecycle. Part of the complexity in understanding the cost involved with systems engineering is due to the diversity of definitions used by different systems engineers and the unique ways in which systems engineering is used in practice. |
| 27 | DSMC, Systems Engineering Management Guide, Defence Systems Management College, Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. (1990, pp12) | Management Guide | Defence Systems Management College | 1990 | The application of scientific and engineering efforts to<br>(a) transform an operational need into a description of system performance parameters and a system configuration through the use of an iterative process of definition, systensis, analysis, design, test, and evaluation<br>(b) integrate related technical parameters and ensure compatibility of all physical, functional, and program interfaces in a manner that optimzes the total system definition and design<br>(c) integrate reliability, maintainability, safety, survivability, human engineering, and oher such factors into the total engineering effort to meet cost, schedule, supportability, and technical performance objectives. |

| S/N | Source | Nature of Source | Author | Year | Definition of Systems Engineering |
|---|---|---|---|---|---|
| 28 | U.S. Department of Defense Regulation 500.2R | Regulation | U.S. Department of Defense Regulation | 2002 | An approach to translate operational needs and requirements into operationally suitable blocks of systems. The approach shall consists of a top-down, iterative process of requirements analysis, functional analysis and allocation, design synthesis and verification, and system analysis and control. Systems Engineering shall permeate design, manufacturing, test and evaluation, and support of the product. Systems Engineering principles shall influence the balance between performance, risk, cost and schedule. |

# APPENDIX B. IRB APPROVAL

**Naval Postgraduate School**
Institutional Review Board (IRB)

22-Sep-08

From: LCDR Paul O'Connor, PhD
To: Lecturer Gary Oliver Langford
Roy Alphonso de Souza

Subject: YOUR PROJECT: MATURITY CURVE FOR SYSTEMS ENGINEERING

1. The NPS IRB is pleased to inform you that the NPS Institutional Review Board has approved your project (NPS IRB# NPS20080072-EP7-A).
2. The NPS IRB was originally certified by BUMED on 26 July 2002 and has been re-certified until 30 August 2009.
3. This approval is valid for one year from this date. Please submit a copy of all records and consent forms to the Research and Sponsored Programs Office (Laura Ann Ikner-Price, Halligan Hall, Room 201B) at the conclusion of this project.
4. If your protocol changes at any time, you will need to resubmit your project proposal to the NPS IRB.

Under 32 CFR 219.116(d), the IRB finds that the requirement to describe procedures may be altered so that subjects receive the attached debriefing information after their participation.

Sincerely,

LCDR Paul O'Connor, PhD
Chair
NPS Institutional Review Board

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